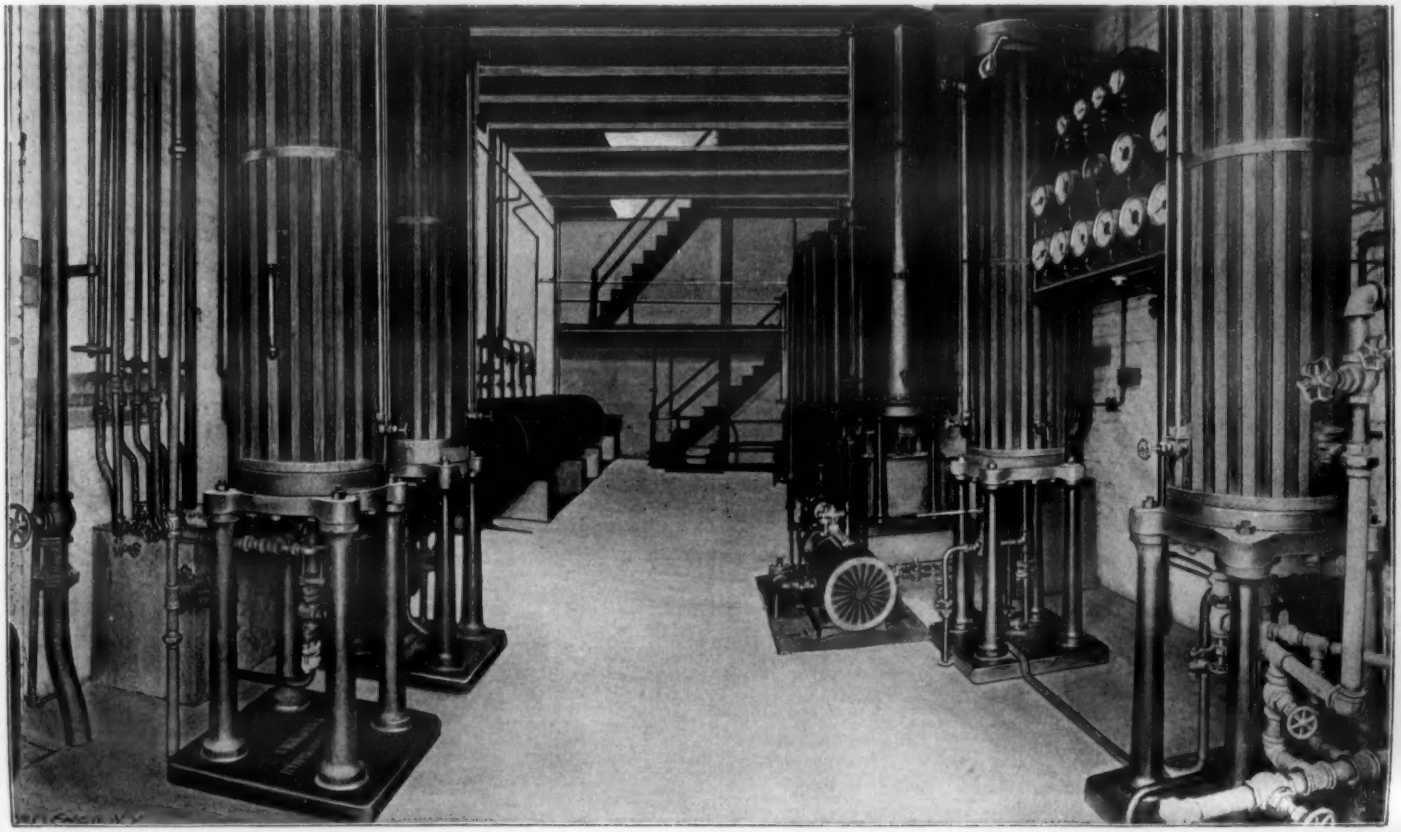

INTERIOR VIEW OF POWER HOUSE, COLORADO AUTOMATIC REFRIGERATING COMPANY, DENVER, COL., 1889.

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ARTIFICIAL REFRIGERATION THROUGH STREET PIPE LINES FROM CENTRAL STATIONS.

BY DAVID BRANSON.

[*Read at the stated meeting of the Institute, November 15, 1893*]

The methods of distribution from central stations through street pipe lines, or wires, of water, light, power, heat and speech, have all been made somewhat familiar to the public by years of common usage. That of distributing power to produce cold is known to comparatively few, and in its latest development, made during the past four years, is, as yet, almost unknown.

A popular idea prevails that we furnish cold air. As a matter of fact, we do not send out cold air, or anything cold, through our pipes. All such methods have been, and must be, financial failures, in spite of the most costly insu-

lation, because of the percentage of loss of cooling power through absorption of heat from the earth or air through which the pipes pass.

Correctly speaking, our business is not to furnish anything; but to remove from the premises of our customers two things of which they wish to be rid—heat and humidity.

The most suitable material, as well as by far the cheapest, which can safely be used as a heat extractor, is ammonia. It conveys heat to the central station, where the heat is disposed of through an application of cold water; and the water, after being thus loaded with heat, is ordinarily discharged into the sewer.

To make the illustration more clear to those having no knowledge of ice-making or refrigerating machines, it might be well to explain by saying that expanding ammonia absorbs heat and that water absorbs ammonia, just as a sponge absorbs water. One might say that water is a sponge for ammonia, and ammonia is a sponge to sop up heat.

Since the first practical development of artificial refrigeration and its application to the cooling of breweries and packing-houses, and to ice making, it has been the dream of many inventors, and also the aim of industrial promoters, to achieve a practical, safe and economical method of distributing refrigeration. Some twenty or more costly efforts to accomplish this result had been made in a dozen different cities, including Paris, London, New York, Boston, Louisville and Nashville. These resulted either in failure or in only partial success, but there was a great gain of valuable knowledge of the difficulties to be overcome, with little knowledge of how to overcome them, until five years ago, when Messrs. Starr, Thornburgh and Branson, the inventors of the system which we are to discuss this evening, undertook to study the causes of the failures of their predecessors.

Fortifying themselves with all the data that could be obtained, they experimented extensively, and visited many of the wrecks of other experiments.

The result has been a series of inventions which have been put into practical operation on a commercial scale in the cities of Denver and St. Louis. The plant in Denver

was started on the eighth of August, four years ago, and has not been obliged to stop a single day since, though it has been twice enlarged and the street line extended. The street line in St. Louis has also been operated for more than three years. Both plants give such satisfaction to their patrons that many would not return to the use of natural ice could they procure it for nothing.

Let me quote from an able article by John E. Starr, which appeared in the *Engineering Magazine* for April, 1893:

"Up to the introduction of the pipe-line system, only those who required large amounts of heat to be transferred could afford the appliances necessary to effect such transfer without using ice as an intermediary. To such large consumers of cooling power the introduction of ice machinery has been of incalculable value. In the brewing, meat-packing, dairy and cold-storage warehouse industries, the refrigerating machine saves annually millions of dollars, and renders possible operations on an enormous scale. To secure to the smaller consumer the benefits, and to the vendor the profits, of mechanical refrigeration was the problem of the pipe line engineer. The general economical advantages required to be preserved may be stated as follows:

(1) "The realization of enormous economy by operating in such a way as to transfer the heat directly from the customer to the central station without using ice as an intermediary.

(2) "The great economic advantages in distribution.

(3) "The general advantage of producing power on a large instead of on a small scale.

(4) "The commercial advantage of being able to offer to the smallest consumer of refrigeration all the benefits and economies of artificial refrigeration now obtained only by large consumers.

"To explain more specifically the first of the above considerations, it may be said that all refrigerating machines have two ratings, one known as their 'refrigerating capacity,' expressed by stating how much ice must be melted to produce an equal cooling effect; and the other as their 'ice making capacity.' The latter is usually placed, at the out-

side, at only sixty per cent. of the former; that is to say, if we have a refrigerating machine that will produce as much cooling power as could be obtained from 100 tons of ice if placed directly at work on the space to be cooled, this machine would manufacture only sixty tons of ice. This may be more readily understood when it is remembered that in ice making the water which is to be frozen has first to be cooled by the machine from a temperature of 80° or 90° F. to the freezing point, before the process of congelation begins. This loss, together with the absorption of heat in and around the ice-making tank, makes up the forty per cent. difference; and this is why all refrigerating machines are catalogued commercially with the two ratings mentioned.

"In the pipe-line process the refrigerating machine is put directly at work on the spaces to be cooled. When a central plant has the equivalent of 100 tons of ice to deliver to its customers, the artificial ice plant has, with the same machine and the same expenditure in coal and engineer's wages, but sixty tons to deliver. This leads to the second consideration. The sixty tons of artificial ice, with the expense mentioned, are delivered only at the factory door. The 100 tons at the station have been delivered to the customers.

"The delivery of ice, even to large customers, is one of the principal factors of cost, while to smaller consumers, say of from fifty to 500 pounds per day, the delivery is by far the greater portion of the cost. The service of ice requires usually a team of horses, a wagon, and two men for delivery in a comparatively limited district, and the cost of delivery by this method usually ranges from fifty cents per ton for the larger consumers up to $2.50 per ton for the users of small pieces of from ten to 200 pounds per day. This large 'operating cost' of delivery, which, to the ice dealer, is an item of expense, becomes to the pipe-line company an item of profit. The upkeep, or repair, account, is little, if any more, by the pipe-line method than by the horse and wagon system of delivery."

At the outset of our attempt to construct and operate

our street pipe-line system, we found that the principal obstacles were:

(1) The loss of power by absorption of heat from the earth.

(2) The difficulty of handling the constantly changing refrigerating load.

(3) The occasional stoppage of service of an entire district by reason of fire or breaks in the line, through accident, or the necessity of making new connections.

(4) The automatic regulation of temperature.

(5) The leakage of the volatile material used as a refrigerating agent.

The absorption of heat from the earth is avoided by what is known as a direct expansion system, in which the liquid anhydrous ammonia (usually at a pressure of 150 pounds to the square inch at summer temperature), flows from the machine through one pipe (the liquid line) to the point of use, and is there expanded by being allowed to flow through a small hole, in a carefully adjusted valve, capable of being regulated to suit the amount of refrigeration required. This expansion takes place in a coil of pipe, within the space required to be cooled, which pipe is known as the expansion coil; and from this coil the anhydrous ammonia, now changed to a vapor, returns through a larger pipe (the vapor line) to the central station. By this system, the entire cooling power of the machine is delivered and utilized in the refrigerators of the customers, none being lost on the way. The pipes, with the exception of the expansion coil, remain at the temperature of the ground or air through which they pass.

Our predecessors had managed fairly well to provide regular temperatures in large establishments under the changing conditions of the seasons, or of day and night, by increasing or lessening the number of machines in operation or the speed at which a single machine was operated. But this had its limitations both financial and mechanical.

In the street pipe-line business this difficulty is increased tenfold. Experience soon taught us that no possible calculation could enable us to predict when the demand upon the

machine would suddenly rise tenfold, without a moment's warning, or as quickly fall to practically nothing.

To provide against this difficulty, we introduced one reservoir (for liquid anhydrous ammonia) at the outgoing end of the machine, a second reservoir (for strong aqua ammonia) at the incoming side of the machine, and a third (for weak aqua ammonia), which is usually placed at a higher elevation.

When the strong aqua ammonia reservoir is full, both others are empty, as their contents are supplied by the separation of the ammonia or the greater part of it, from the water originally holding it in the strong aqua ammonia reservoir. The contents of this reservoir are pumped into the still at a uniform rate, and from the still the pure ammonia passes through the condensing coils to the reservoir for liquid anhydrous ammonia and the water or weak ammonia remaining flows to its reservoir above, each impelled by the pressure obtained from the heat of the distilling process.

The contents of the weak ammonia reservoir flow by gravity to the absorber automatically, as required, and absorb the returning anhydrous ammonia vapor from the street line.

As we use what is known as an absorption machine (because compression machines have been found impracticable for this purpose) the anhydrous ammonia vapor returning from the line is first discharged into a tank of peculiar construction, called an absorber, where it is reunited with the weak aqua ammonia from which it was originally driven by distillation. When this aqua ammonia has absorbed all of the anhydrous ammonia vapor that it is capable of holding, it is automatically discharged into the reservoir for strong aqua ammonia, from which it is again pumped into what is known as the still or separator.

By this reservoir system several objects are accomplished; first, a machine of half the size that would otherwise be needed will answer for any required amount of service; as it will readily be seen that without the reservoir, a machine would have to be of sufficient capacity to perform the ser-

vice called for during the hottest hour of the hottest day, while during other hours a machine of one-tenth the capacity would often be ample.

In the reservoir system, the machine operates steadily throughout the twenty-four hours, while the reservoirs vary in the amount of their contents alternately as the demand reaches a rate greater or less than the average of the machine.

This system also enables us to shut off the machine entirely for short periods to make repairs, and in cold weather, to dispense with a night force entirely, allowing the reservoir and the absorber to work automatically, without attention.

Of course, in very large cities, multiples of the largest sized machine would be used with reservoirs of sufficient size to give steadiness to the operation of either machine and to permit of short stoppages.

Our third great difficulty was overcome by providing a vacuum or safety line, which is a vital part of the system; for, without it, continuous operation could not be secured, nor could necessary repairs be made. This vacuum line is a third pipe connected with the liquid and vapor pipes, at or near their entrance to each refrigerating box supplied, and also in the man-holes at the street crossings.

In case of necessary repairs, alterations or additions to the pipes in any premises, the stop-cocks on the liquid and vapor pipes are closed, and the cock on the vacuum line (which has been habitually kept closed) is opened, the vacuum pump is then started at the station, and thus the ammonia contained in the expansion coil is drawn back to the central station and a ten or fifteen-inch vacuum is also usually produced. Then the piping in the refrigerating box may be opened without any smell of ammonia escaping.

By the same method, any section of the main line may be cut into for additional connections or repairs, by means of opening and closing cocks in the manholes at street crossings.

In our later work we have made the vacuum line of such size that it can be used as a temporary substitute for either

the liquid or vapor line, during alterations, thereby enabling us to avoid cessation of service to any customer even for an hour.

By keeping a constant vacuum, the contents of any expansion coil or any section of the line may, without previous notice to the engineer, be promptly switched into the vacuum line from any place where trouble has occurred, especially in case of fire or break in the street, and thus the material liable to be lost is quickly saved, as the engineer at the works will immediately start the vacuum pump, upon his attention being called thereto by an electric bell rung by the movement of the hand on the dial of the vacuum gauge.

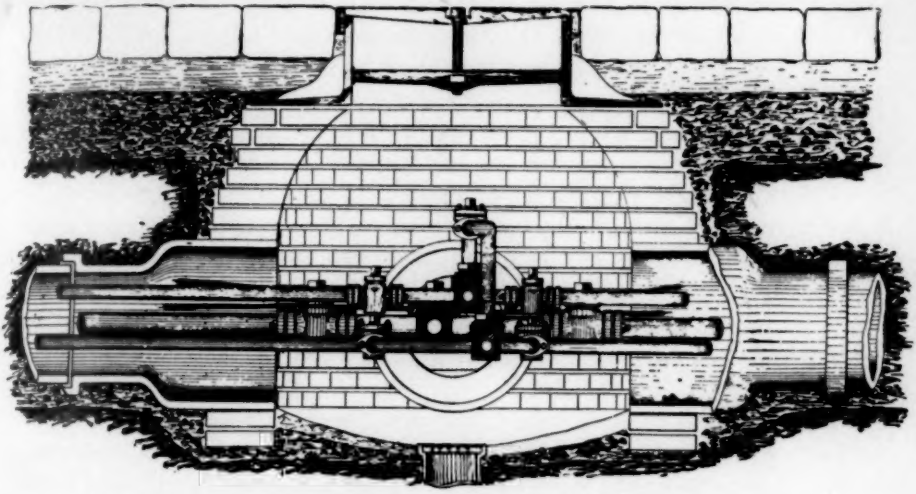
The advantages of this vacuum line are also very apparent when it becomes necessary to shut off a customer, and pump home the contents of his expansion coil, and leave him out in the hot for non-payment of his bill.

In the matter of automatic control we had to solve the problem of supplying all degrees of temperature, not only on the same branch line or street, but often three or four in one building, or even in the different compartments of one refrigerating box; varying from ice-making and fish-freezing, up to the very easy task of keeping rooms for furs and woollen goods free from moths, or taking a few degrees of heat and humidity from a restaurant dining-room, a public hall, business office or hospital.

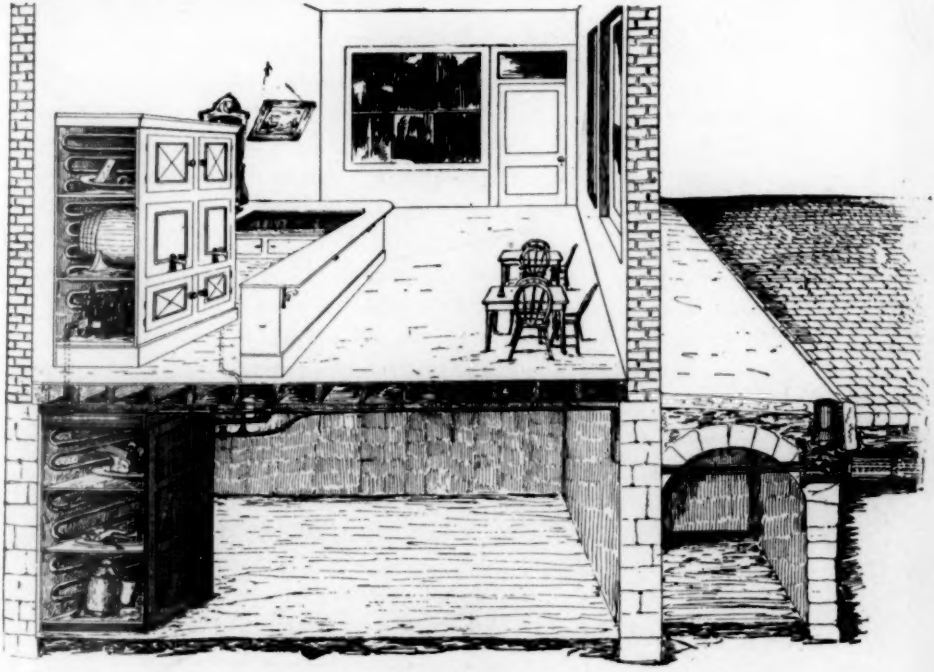
To do this, numerous devices were invented and tested —nearly all with brilliant success at the start; only to be followed by dismal failure when put to the test of time and innumerable changing conditions.

They choked up, froze up, gummed up and broke up in every imaginable way. But, one by one, the weak points were weeded out, the strong features combined; until, finally, two forms of regulators were constructed, both of which have stood the test of every possible condition we could think of through the changing requirements of spring, summer, autumn and winter.

These automatic valves are operated by electric power supplied from a dynamo through a storage battery at the



SECTIONAL VIEW OF MANHOLE, SHOWING ARRANGEMENT OF PIPE LINES.



INTERIOR VIEW—SHOWING ARRANGEMENT OF SERVICE SYSTEM.

The question of measurement of the amount of service rendered has been solved in two ways:

First, by a meter, measuring the quantity of liquid ammonia passing into each expansion coil. Knowing as we do the heat-extracting power of a pound of ammonia expanded under any given condition, it is a simple matter to calculate the equivalent, in ice melting, of the service rendered.

Up to the present time, no cheap meter has been made for the measurement of ammonia, which is even as satisfactory as the ordinary illuminating gas meter; and we hope for something less costly for this purpose before undertaking general household service.

The second method of estimating the amount used is the measurement of the square feet of the interior surface of the refrigerating box or room, and the figuring out of the amount of heat removed therefrom, by the aid of a set of tables carefully prepared by means of a long series of experiments with every known form of insulation now in general use for refrigerating boxes.

By these experiments we have ascertained, as to each material and thickness, how many units of heat will pass through a square foot of service in twenty-four hours for each degree of difference between the average inside and average outside temperature. To this we add a small percentage (based on experiments) for the amount admitted by the opening of doors, and the placing of hot materials in the refrigerator.

The entire cost of street-line construction varies from $9,000 to $22,000 per mile, depending upon the character of the street-paving, which has to be removed and replaced, the kind of soil to be excavated, the crowded or free condition of the ground under the streets from other piping, etc., the correctness of the city records as to old work in the same, and the amount of street traffic interfering with operations. The highest cost has been in narrow, crowded business streets in St. Louis, Mo., where the paving is very expensive, and where there was a net-work of both old and new pipes, of many of which no correct record existed in the city

archives. This frequently necessitated the changing of plans after the streets had been opened. In a city with pavements of average character, the cost, including branches to the sidewalk, ready for service connections to the num-

REFRIGERATING PIPE LINE, IN PROCESS OF CONSTRUCTION, SIXTH STREET, ST. LOUIS, MO., JUNE, 1891.

Showing the open trench in which is first laid the lower half of each section of vitrified clay pipe which forms the conduit in which the wrought-iron pipes conveying ammonia are laid upon suitable brackets. These brackets also support the insulated copper wire for the electric circuit.

ber of 100 to the mile, will be about $18,000 in business neighborhoods, and about $14,000 in residence districts where the lines can generally be run through back streets containing no other pipes.

A power house* with duplicate machines to operate two or three miles of street line in a business locality, should not exceed in cost $90,000. In large cities it would be better to build a larger plant, say one costing $200,000, with five or six cooling machines of daily capacity of 100 tons each. This should take care of five or six miles of street line. Should it be required to cover more ground than this, in very large cities, it would probably be better to build another plant at a distance not exceeding two miles from the first. The limit of practical working distance is about the same as with illuminating gas.

It is immaterial whether the plant be on low or on high ground, or whether the lines run down or up hill, or both, alternately. It can be operated on any floor of a building, from cellar to garret; and it is now supplying cold on the second floor of a large hotel some thirty feet above the street line and fifty feet above the central station. We have made no failure in any kind of cooling operations that we have attempted. These have covered nearly the entire range of cooling work (including ice making in the buildings of customers at long distances from the works).

We have, so far, charged prices varying from ten to twenty per cent. less than would be paid for ice sufficient to furnish an equivalent amount of cooling. In addition to that saving in their ice bills, customers have avoided slop, wear and tear, and have saved the cost of labor in handling ice. We also give them much more uniform service, and in many cases do work which it is impossible to do with ice; especially continuous and hard freezing and furnishing dry cold where damp cooling with ice would be ruinous.

While it is, of course, not only probable, but certain that numerous improvements will be made in the apparatus, from time to time, they will be mainly in the line of minor

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* The frontispiece shows an interior view of the power house of the Colorado Automatic Refrigerating Company, in Denver, erected in 1889. Horizontal tank, strong aqua ammonia reservoir. Upright tanks near the stairway, liquid anhydrous ammonia reservoir. The largest upright cylinder is the absorber. Cylinders in the foreground on each side are stills and exchangers. The weak aqua ammonia reservoir is on top floor.

economy; the system itself, and general operation being substantially perfected. The repairs on the work constructed two years ago, after we had finished experimenting on the original trial lines, have been only nominal, and the loss by leakage small, and this due to the carelessness of employés. By the improved fittings, leakage has been made almost impossible.

We operated, at first, with machines of twenty to thirty tons daily capacity; and continued to do so until more than two years ago, when a ninety-ton machine was added in St. Louis. This has been working successfully ever since, and a duplicate has since been used in connection with it. Another of the same size was put in operation eighteen months ago in Denver, and is working satisfactorily. The old machines are being utilized in the business of ice making; and at the same time are in readiness to take care of the street-line work in case the new machines should by any chance get out of order; in which event, the ice-dealers only would have to fall back on their store of natural ice.

The USE of STEEL in ELECTRIC MACHINES.

By H. F. Parshall.

During the last few years steel has come to be used largely in the magnetic parts of electrical machines. In the magnet frames of some classes of machines the changes brought about have been most marked. In armature cores which require thin plates there has been no change, since the requirements are so rigid that the properties, either physical, or chemical, of steel, differ but little from wrought iron; in fact, the distinction between steel and iron in this case is made on account of the difference in the processes of steel and iron making.

By the use of steel in magnet frames street-car motors have been so completely changed that the motors of to-day, so far as form and appearance go, are hardly comparable with those of a few years ago. Before it was possible to

get steel castings of complex form, street car motors were limited to such forms of construction as could be built up with elementary blocks of forged iron.

How great the change has been is evident upon examination of *Figs. 1, 2, 3* and *4*. *Figs. 1* and *2* show two early

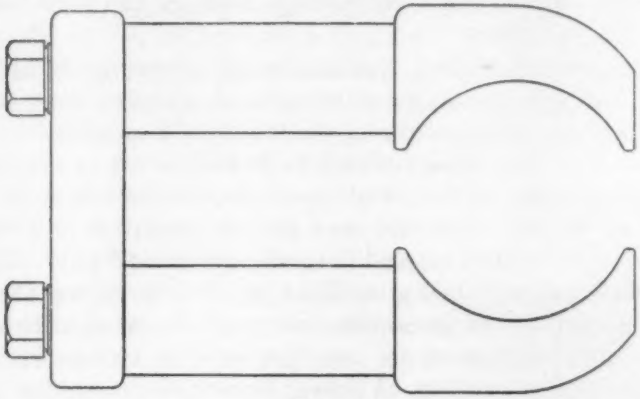


FIG. 1.

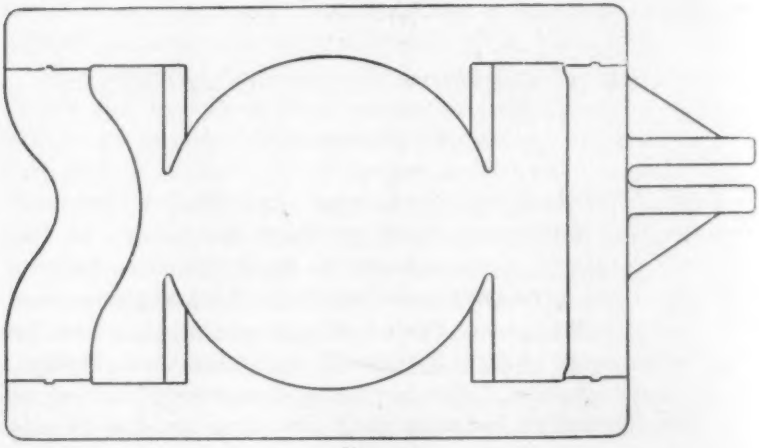


FIG. 2

types of street-car motors that have been widely used, that were constructed from the forms of iron obtainable when the machines were designed. *Figs. 3* and *4* show the outlines of a modern street-car motor constructed of steel castings. It will be noticed that a water-proof casing has

been cast with the magnetic circuit, that the motor is much more compact, and that the parts liable to mechanical injury are thoroughly protected. The forms of motor practicable to build from forgings do not lend themselves well to single reduction, while with the steel castings now obtainable,

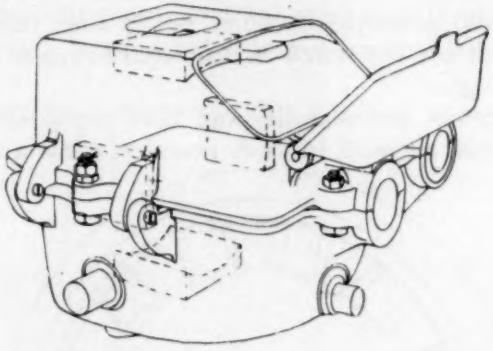


FIG. 3

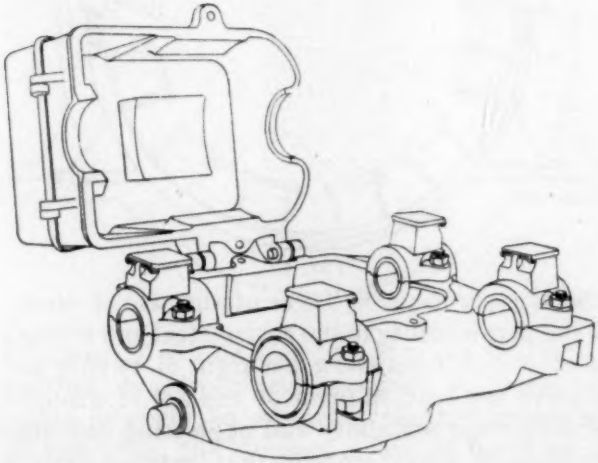


FIG. 4.

single reduction motors are easily constructed and economical of material.

Further, owing to the range of form permissible, it is possible to arrange the parts so that the length of the magnetic circuit is shortened, thereby diminishing the weight

of the motor about twenty per cent. to the advantage of repairs on track and trucks.

In stationary motors corresponding changes have been made, or are now contemplated. In the case, however, of generators the advantages obtainable from the use of steel are less marked, both from the standpoint of form and of economy, the principal reasons being that this class of machinery is not restricted as the above classes as to size, form, or weight.

The ratios of permeability and cost per pound of steel and cast iron, as used in best practice, show a margin of

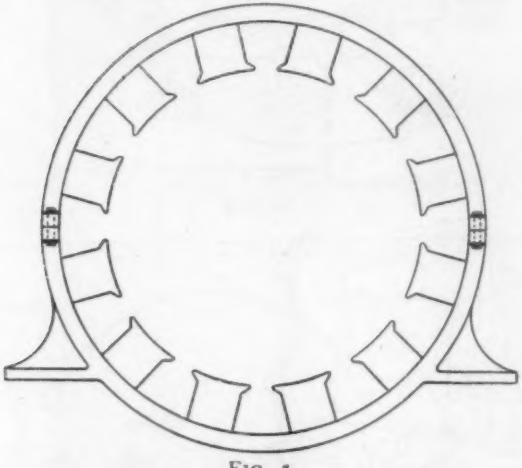


FIG. 5.

about twenty per cent. in favor of the use of steel. The ratios of the permeability to the cost of steel and wrought iron forgings of simple form show a margin of twenty per cent. to twenty-five per cent. in favor of the use of wrought iron.

Reasoning from the above and neglecting any difference in machining, it would appear that magnet frames constructed entirely of steel would be cheaper than those constructed of cast iron. Further, the difference is considerably increased on account of the greater amount of copper required in the magnetizing coils of a cast-iron machine, this increase being due to the greater length of turn of the magnetizing coils on account of the greater section of the

cast iron required to support a given magnetic flux. In the conditions obtaining at the present time steel magnet frames and magnetizing coils cost only about seventy-five per cent. of magnetically equivalent cast-iron magnet frames and magnetizing coils.

It would further appear from the ratios given above, of the permeability and cost of steel and forgings, that a magnet frame constructed of forgings would be the cheapest of all.

By referring, however, to *Fig. 5*, which shows a typical

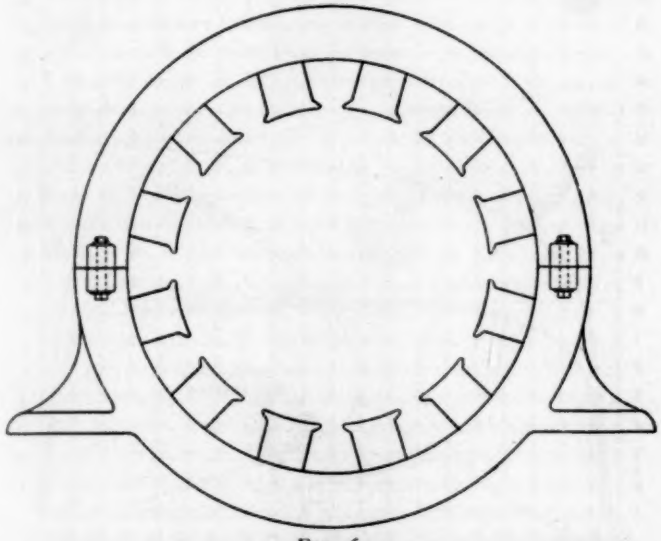


FIG. 6.

magnet frame, it will be seen that it is not practicable now to construct dynamo frames entirely of forgings. It is practicable, however, to construct magnet frames with the yoke of cast iron, the magnet cores of forgings and the polar projections of cast steel, as is shown in *Fig. 6* on the same scale as *Fig. 5*. Such a structure costs about the same as one entirely of cast steel, and possesses the advantage that both cast iron and forgings are more uniform in magnetic qualities, easier to machine, require less chipping and are more easily finished. There is, however, the disadvantage

that the weight of cast iron as used in practice is about two and one-half times that of steel for same magnetic results, and thus the parts that can be made of cast iron are in many cases very massive and difficult to move.

As a practical example, we will take the 1,500 kilowatt generator, recently designed for the General Electric Company, and now in operation in the Brooklyn Railway Station. The magnet yoke is constructed of steel and weighs 38,000 pounds. If it were constructed of cast iron it would weigh

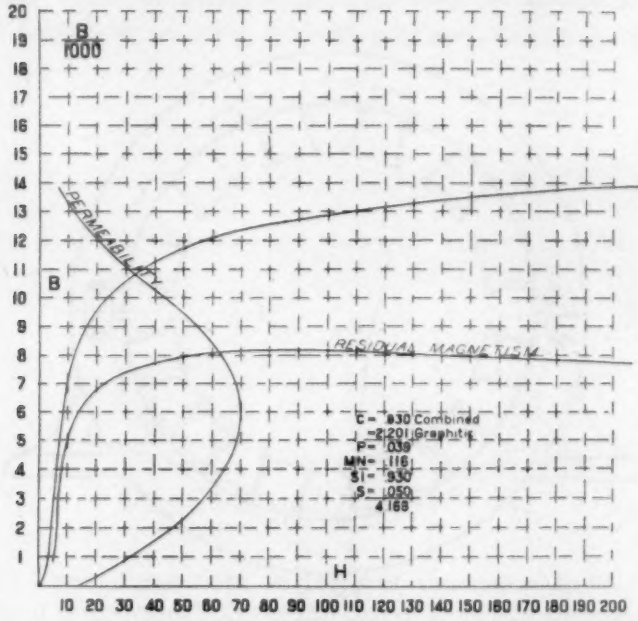


FIG. 7.

87,000 pounds, such a weight requiring extraordinary facilities both as to shipping and handling in the shop.

We will now consider the quality of steel required for magnet frames, meaning by steel such combinations of iron as can be cast and are free from uncombined carbon or graphite. The effect of combined carbon or graphite is to lessen the magnetic continuity and greatly lessen the permeability.

Figs. 7 and *8* have been included to illustrate the mag-

netic effect of the presence of graphite even though, by the above definition, graphitic irons are not directly in the line of the present discussion.

It is the practice of the General Electric Company to make a chemical analysis of a sample of the steel in each casting before it is used in construction. This was occasioned by the considerable variation found in steel made, apparently, under the same conditions. In one notable case the amount of copper in the magnet coils of a large genera-

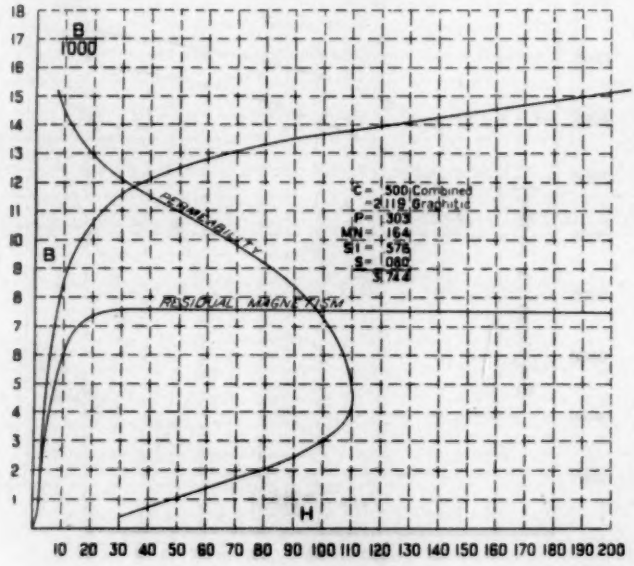


FIG. 8.

tor had to be increased thirty per cent., owing to the presence of innumerable blow-holes throughout the yoke and pole pieces. An examination of a great number of these analyses does not indicate clearly the relation between the chemical and magnetic properties. The particular value of such analysis seems to be from the clue furnished to the physical properties, *i. e.*, as to the probable softness and homogeneity of the steel.

It may, however, be roughly stated that good cast steel

should not have greater percentages of impurities than are given in the following analysis:

Carbon,	·25
Manganese,	·60
Silicon,	·20
Phosphorus,	·08
Sulphur,	·05

In practice, carbon is the most objectionable impurity, and can to advantage be restricted to smaller amounts than above quoted. The results of a great number of tests and

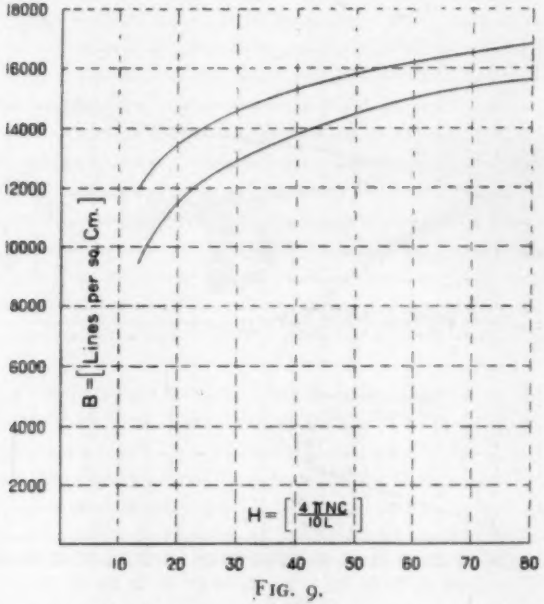


FIG. 9.

analyses were plotted, and it appeared quite evident that the falling off of permeability was proportional to the amount of carbon contained and by diminishing the amount of carbon, other conditions remaining the same, there was a corresponding increase of permeability.

Manganese below ·6 per cent. seems to have but little effect. The presence of manganese in large quantities deprives the steel of nearly all magnetic susceptibility, a twelve per cent. mixture having scarcely greater magnetic susceptibility than air.

Silicon at the magnetic densities used in practice is less objectionable than carbon, but at high densities it appears to diminish the magnetic qualities of iron to some extent. Its presence is objectionable in that it facilitates the formation of blow-holes, and like manganese, has a hardening effect, rendering the steel hard to tool.

Phosphorus and sulphur, limited to the amounts stated above, are not objectionable.

In *Fig. 9* the upper curve shows what in ordinary practice

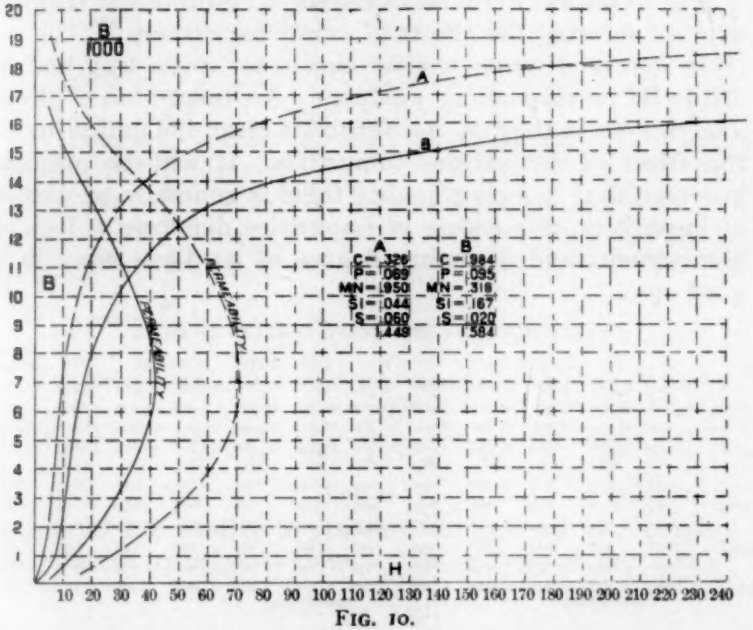


FIG. 10.

is termed good steel, the lower curve shows what is termed poor steel. Corresponding analyses are shown in Tables I and II.

TABLE I.—DATA OF TEN FIRST QUALITY SAMPLES OF CAST STEEL.

	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*VII.*	*VIII.*	*IX.*	*X.*	*Average.*
B for H = 15,	12,200	12,000	12,100	12,900	13,000	12,300	13,100	12,100	12,600	13,000	12,500
B for H = 25,	14,100	13,600	13,900	14,400	14,600	13,900	14,500	13,700	14,200	14,500	14,100
B for H = 50,	15,800	15,300	15,600	15,900	16,600	15,600	16,100	15,400	15,800	16,000	15,800
B for H = 75,	16,600	16,200	16,600	16,500	17,600	16,400	17,100	16,300	16,700	16,600	16,700
Carbon, . . .	·240	·267	·294	·180	·290	·250	·200	·230	·170	·180	·230
Phosphorus, .	·071	·052	·074	·047	·037	·093	·047	·100	·089	·047	·057
Silicon, . . .	·200	·236	·202	·120	·036	·230	·170	·160	·150	·120	·195
Manganese, .	·480	·707	·655	·323	·550	·410	·530	·450	·390	·323	·482
Sulphur, . .	·040	·060	·050	·050	·050	·030	·030	·040	·020	·050	·042

TABLE II.—DATA OF TEN SECOND QUALITY SAMPLES OF CAST STEEL.

	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*VII.*	*VIII.*	*IX.*	*X.*	*Average.*
B for H = 15,	10,600	10,600	10,700	9,000	9,300	10,000	10,400	10,000	9,300	11,300	10,120
B for H = 25,	12,700	12,700	13,100	11,200	11,600	12,100	12,500	12,400	11,800	13,500	12,360
B for H = 50,	14,900	14,600	15,100	13,500	13,900	14,300	14,400	14,700	14,100	15,700	14,520
B for H = 75,	15,900	15,600	15,900	14 400	14,900	15,300	15,300	15,700	15,000	16,500	15,450
Carbon, . . .	·250	·280	·195	·333	·337	·366	·409	·318	·702	·380	·357
Phosphorus, .	·087	·076	.028	·059	·045	·151	·063	·107	·084	·066	·077
Silicon, . . .	·210	·210	·683	·292	·302	·476	·444	·223	·409	·530	·378
Manganese, .	·790	·720	·815	·681	·642	·617	·640	1·636	·088	·790	·742
Sulphur, . .	·020	·030	·040	·060	·070	·040	·010	·030	·050	·030	·038

Fig. 10 shows curves and analysis of two different samples of steel showing the effects of combined carbon.

In *Fig. 11* is given similar curves for mitis iron and in Table III corresponding analyses. An inspection of these analyses show they do not furnish a clear indication as to the effect of the various impurities. It will be noticed, however, that in a poor quality there is generally an excess of impurities, this excess of impurities denoting a lack of homogeneity and a greater degree of hardness than in a good steel.

TABLE III.—DATA OF TWELVE SAMPLES OF MITIS.

	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*VII.*	*VIII.*	*IX.*	*X.*	*XI.*	*XII.*	*Average.*
B for H = 15,	12,600	14,500	14,500	12,700	13,900	14,200	14,020	10,800	10,000	12,900	12,700	11,800	12,900
B for H = 25,	13,600	15,600	15,700	14,500	15,000	15,700	15,300	12,650	11,900	14,300	14.300	13,400	14,300
B for H = 50,	14,800	16,900	16,700	16,200	16,300	16,800	16,500	14,300	13,900	15,900	16,000	15,000	15,800
B for H = 75,	15,500	17,600	17,500	16,900	17,000	17,400	17,100	15.200	14,800	16,800	16,800	15,700	16,500
Carbon, . .	·065	·105	·106	·125	·136	·212	·214	·216	·235	·241	·242	·260	·180
Phosphorus,	·083	·093	·112	·166	·053	·056	·052	·128	·065	·093	·094	·130	·093
Silicon, . . .	·073	·045	·050	·046	·111	·126	·111	·083	·122	·072	·099	·020	·080
Manganese, .	·112	·108	·099	·120	·191	·405	·401	·167	·107	·248	·253	·140	·196
Sulphur, . .	·150	·050	·050	·050	·030	·040	·040	·010	·030	·030	·030	·030	·045
Aluminum, .	·079	not determined.	·059	·183	·008	·273	not determined.			·152	·035	·120	·119	·080	·113

The effect of annealing on the permeability of cast steel varies considerably, according to the treatment at the foundry. In an ordinary sample annealing seems to increase the permeability for low magnetizations, but for high magnetizations the effect is less marked.

The effect of tempering is to greatly diminish the permeability.

Results of an interesting experiment illustrating the intimate connection between the physical and magnetic properties of steel are shown in *Fig. 12*. Curve 1 shows a

test of sheet steel as received. Curve 2 shows test of same after annealing. Curve 3 shows test of the same sample after being subjected to a pressure of 40,000 pounds per square inch. It will be noticed that the annealing in this case materially increased the permeability, but that the sub-

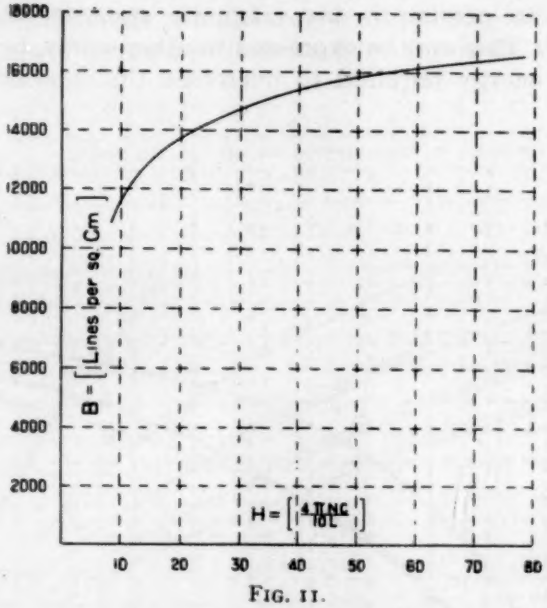


FIG. 11.

jecting of the sample to pressure diminished the permeability below its original value. The analysis of this test is:

$$\begin{aligned} C &= \cdot 049 \\ P &= \cdot 117 \\ Mn &= \cdot 369 \\ Si &= \cdot 202 \\ S &= \cdot 1 \end{aligned}$$

We will next consider the quality of steel that is most suitable for plates of armature cores. These plates in ordinary practice vary from ·014 inch to ·030 inch in thickness; in consequence, steel has to be of very good quality, mechanically, otherwise it would not withstand the rolling process. There is very little difference between the chemical

analysis of the steel that is ordinarily used in these plates and wrought iron. In general, plates made by the steel process show more manganese, and those made by the iron process show more silicon; in fact, these are the clues that serve in practice to identify the processes. Steel to be of the most satisfactory quality must have a minimum tendency to persist in any magnetic state it may have acquired. This may be expressed in other words, by saying that the energy required to overcome the intermolecular

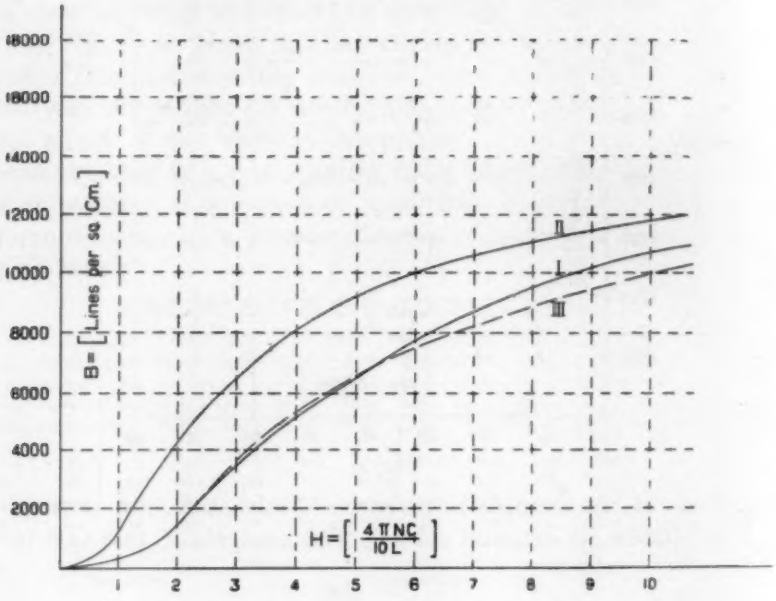


FIG. 12.

friction brought about by changing the direction of magnetization of the iron should be a minimum. This tendency to persist in a formerly acquired magnetic state is termed hysteresis, and the amount of hysteresis is measured by the amount of energy required to completely reverse the direction of magnetization.

In *Fig. 13* are given a number of curves for different cycles, showing how hysteresis varies with the intensity of magnetization in ordinary quality sheet steel.

It is most difficult to determine the effect of the chemical constituents upon the hysteretic loss in sheet iron and steel. This is owing to the fact that with the usual compositions low in silicon, a very slight difference in the annealing will make a disproportionately great difference in the hysteretic loss, and as it is a matter of great difficulty to subject different samples to even approximately similar conditions of annealing, it is hard to illuminate this large

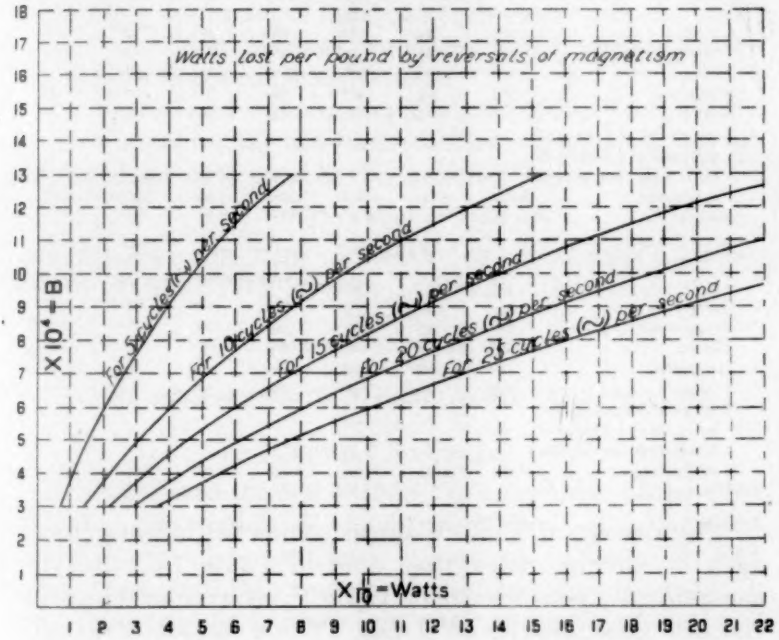

Watts lost per pound by reversals of magnetism
X 10⁴ = B
X 10 = Watts
for 10 cycles (~) per second
for 15 cycles (~) per second
for 20 cycles (~) per second
for 25 cycles (~) per second

FIG. 13.

variable effect sufficiently accurately to determine at all satisfactorily the residual effects of the chemical constituents.

Silicon in the proportions occurring in sheet iron and steel is not very harmful except that it tends to prevent to a certain extent the improvement that would otherwise result from annealing.

Manganese and sulphur up to a considerable amount (·6 per cent. for manganese, and ·06 per cent. for sulphur) do not increase the hysteretic loss.

From the tests made up to the present time the following conclusions seem warranted. Phosphorus is especially objectionable as regards the hysteretic loss and has more tendency to increase the hysteretic loss than carbon.

Two tables are given below, showing the amount of energy dissipated per cycle, first in six exceptionally good samples, and second in six exceptionally poor samples.

TABLE IV.

	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*Average.*
	per cent.						
Carbon,	·076	·085	·072	·086	·095	·078	·082
Phosphorus,	·058	·052	·057	·084	·075	·056	·064
Silicon,	trace	·005	·006	trace	·007	·012	·005
Manganese,	·297	·021	·417	·320	·322	·026	·246
Sulphur,	·060	·030	·030	·040	·030	·010	·033
Ergs per cubic centimeter per cycle at a density of 8,000 lines per square centimeter,	2,800	3,100	2,800	3,000	3,300	3,400	3,070
Material,	sheet iron.		S S	S S	S S	S S	

TABLE V.

	I.	*II.*	*III.*	*IV.*	*V.*	*VI.*	*Average.*
Carbon,	·153	·063	·117	·099	·090	·153	·113
Phosphorus,	·032	·075	·101	·135	·101	·081	·088
Silicon,	·007	·008	·005	·000	·027	·002	·008
Manganese,	·430	·036	·401	·449	·449	·486	·375
Sulphur,	·050	·030	·010	·080	·030	·070	·045
Ergs per cubic centimeter per cycle at a density of 8,000 lines per square centimeter,	8,300	9,000	8,500	8,050	8,000	8,010	8,310
Material,			S I	S I	S S	S S	

The average of Table V shows somewhat larger percentages of all impurities than that of Table IV. But the exceptionally poor results of Table V, as well as the exceptionally good results of Table IV are undoubtedly due largely to the difference in the annealing. Annealing has a tendency to make the structure of the iron more homogeneous, leaving the molecules freer to change their direction. Experiments have been made to show that hysteresis can be lessened from 8,000 ergs per cubic centimeter per cycle to about 2,000 by careful and continuous annealing.

With respect to the use of steel in general for magnetic purposes, it may be stated that the most valuable products are those that are found to be softest and most homogene-

ous. In a given sample any physical change which increases the permeability and correspondingly diminishes the hysteresis. In different samples steel of the highest permeability may not give the best results as to hysteresis; thus a trace of uncombined carbon has a tendency to greatly lessen the permeability, but does not seem to greatly affect the hysteresis.

The most hoped-for improvements in steel are in the making of castings free from blow-holes and surface defects, requiring a minimum of finish, and which are soft and easily machined. Such castings would certainly prove satisfactory from a magnetic standpoint.

In conclusion I wish to express my indebtedness to Mr. H. M. Hobart for the assistance he has rendered in the collection of the data used in this paper.

A PLEA FOR THE STUDY OF ELEMENTARY FORESTRY IN THE LOWER SCHOOLS.

By Edwin J. Houston, Ph.D.

[*A lecture delivered before the Franklin Institute, November 3, 1893.*]

[*Concluded from p. 31.*]

A wide dissemination both of the knowledge of the evils following the removal of the forests, as well as the benefits ensured by their protection is necessary for the public welfare. How shall this much-needed information be given to the general public? How best may these important facts be made matters of common knowledge? I would answer not only by means of suitable literature in books, newspapers, and periodicals generally; not only by means of lectures and addresses, but also, indeed, I believe mainly, by means of proper instruction given to the children of our lower schools.

I would, therefore, urge that elementary forestry be made a study in our lower schools for the following reasons; viz.,

(1) As a matter of public policy, because I believe such study necessary properly to instruct the public through the

children as to the duties it owes the State to insist on the enactment of penal laws for properly protecting the forests in certain sections of the country.

(2) Because I believe that such study can be placed on the curricula of our lower schools without necessitating the introduction of an entirely new study, since it can be made a branch of that basic study of elementary natural science which nearly all agree should form an essential part of the child's early school work.

If the important lesson can thus be given to the child as to the duties it owes to the State in the protection of the forest, not only without interfering with its other studies, but even as a proper and natural expansion of such studies, I feel sure you will agree with me as to the advisability of introducing the study of elementary forestry into the lower schools.

The question naturally arises here, what is meant by the lower schools? Perhaps this title for my lecture is a somewhat misleading one; for, by the lower schools I certainly do not mean anything lower than the schools of a grade intermediate between our primary and grammar grades. I believe the study of elementary forestry can be taken up profitably in schools intermediate in grade to the primary and the grammar, though I believe it could better be taken up in the grammar grades. Of course, it could still better be taken up in the high school or in the colleges or universities; but here the very purpose of the movement would be lost. The main reason for not leaving this study for the schools of the higher grades, arises from the fact that so few of the children ever reach the higher grades, by far the largest proportion numerically leaving school either at the end of the primary or at the end of the intermediate grades. This movement to introduce the study of forestry into the lower schools, being inaugurated mainly for the purpose of teaching this subject to as great a number as possible of the children who are afterwards to become citizens, would thus be rendered ineffectual.

Now, as to the scope of the study of forestry that I would propose for introduction into the schools as low as (say) the

intermediate grades. I should, of course, as I have already stated, make this study of the most elementary character. I wish it to be distinctly understood that I do not advocate the studying of forestry as a formal study necessitating the use of a text-book, unless, indeed, such book be merely as a reader; I would rather make forestry a branch of elementary science (say of geography), or of elementary natural science in general.

I would teach, as far as possible, the general principles underlying the growth of trees and vegetation, the laws regulating the distribution of the sun's heat; the peculiarities attending the evaporation and precipitation of moisture; the general laws of drainage, etc. But it will be noticed that these matters have already been studied in nearly all schools below the grades which we are considering. The children reaching the intermediate grades have already some of these general principles. So far then there is no new study introduced. I would then simply endeavor to show how the presence or absence of a forest covering in any section of country, must necessarily be influential in modifying the distribution not only of the surface drainage, but also of the sun's heat in that section of country, always carefully avoiding debatable questions and ever bearing in mind the age and intelligence of the children to whom the instruction is being given.

That such principles are not too difficult to be properly taught to young children, I think the following synopsis that I would propose for a course of study will abundantly demonstrate. In this synopsis I have carefully avoided all debatable topics, and have introduced only such principles as I believe the child can grasp.

The effects that are generally believed by those who have carefully studied the subject to be produced by the presence of a forest covering are as follows; viz.,

(I) INFLUENCE OF A FOREST COVER ON THE DISTRIBUTION OF THE RAINFALL.

(a) *Tendency of a forest cover to decrease the amount of surface drainage and to increase the amount of subterranean drainage.*

Where a forest cover exists more of the rainfall will reach the lower level by first sinking into the ground and less by running directly off the surface, than if the forest were removed.

The rain which falls on the extended area of a forest, slowly trickles down the trunks of the trees or down the stems or stalks of the undergrowth, and thus finds ready entrance into the ground which is more open and granular than if the trees were removed. The rapidity of surface drainage is decreased by reason of the uneven character of the forest floor, produced by the decaying leaves and vegetable mould, and thus a better opportunity is afforded for the water to sink into the ground.

(b) *Tendency of a forest cover to decrease the amount of evaporation that takes place from the surface of the ground.*

Less of the rainfall will pass directly from the wet earth into the atmosphere, and more will reach a lower level either by surface or subterranean drainage, in a region covered by a forest than in the open, uncovered country.

When the forest cover is removed, more of the rain will pass into the air by evaporation; for, the trees act as a shield partially to prevent this rapid evaporation.

(c) *Tendency of a forest cover to keep the air within the forest somewhat moister than that over the open country.*

Although evaporation is greater in the open country than in the forest, yet the air within a forest is moister than that over the open country, because the removal of the air by winds is less rapid within the forest than it is in the open, uncovered country. According to Fernow, fully half the field evaporation is saved by the presence of the forest. Moreover, during active growth, the forests give off considerable water vapor from their leaves. This amount has been estimated as three times greater than from a water surface. Then, too, in dry weather the trees draw much water towards the surface from the moister, deep-seated strata. All these influences render the air within the forest moister than in the open country.

(II) THE INFLUENCE OF A FOREST COVER ON THE DISTRIBUTION OF THE SUN'S HEAT.

(a) *General tendency of a forest cover to decrease the extremes of temperature both of the soil in which the trees grow and of the air around them.*

Both the soil of the forest and the air within the forest are less subject to rapid heating in summer and rapid cooling in winter than in the open country. This arises from the fact that the covering protects both the soil and the air from direct exposure to the sun's heat, and from direct cooling due to loss by radiation. As a rule, the forest is cooler than the open country in summer, slightly warmer in the spring, and less liable to sudden change throughout the entire year.

(b) *Tendency of the forest cover as a whole to lower the mean yearly temperature both of the soil and of the air within its cover.*

Less of the sun's heat reaches either the ground or the air within the forest than in the open country being absorbed by the leafy canopy forming the upper surface of the covered area. The general effect on both the soil and the air is a cooling one.

(c) *Tendency of a forest cover to delay both the time of early frosts in late autumn and early winter, and the time of excessive high temperatures during the late spring or early summer.*

The general tendency of a forest cover is to decrease the extremes of temperature.

The occurrence of an early frost often causes a great loss to the ripening crops. The delay of a frost by only a week or so may make the difference between a ripened crop and a failure, and may thus mean hundreds of thousands of dollars to the agricultural interests. Late in the summer the air rising from the forests often produce layers of mist over the forest, or in the country near the forest; these layers act as a covering, which prevents the land from losing its heat as rapidly as it would otherwise. Moreover, a forest may act also as a screen to shield the field to the leeward of a cold air. In times of threatened early frosts the forest may, therefore, in these different ways protect fairly distant areas. The difference in temperature so produced may be

but a small fraction of a degree, but if this prevent the occurrence of a frost, how valuable this small fraction!

(III) INFLUENCE OF A FOREST COVER AS A SHIELD OR SCREEN.

(a) *Action of a forest cover as a protection from hot or cold winds.*

The temperature of the air within a forest cover is more equable than in the open country, not only because the cover protects it from direct heating by the sun, but also because this covering protects the air of the forest from the heating or chilling action of the winds.

(b) *Action of a forest cover as a protection of the soil from the denuding action of the rain.*

When fairly large, rain drops strike the ground in the open country with considerable force, but within the forest cover, the ground is protected from this action, not only by the trees but also by the protective covering of the undergrowth or the carpet of decaying leaves, etc., which accumulates in every forest, if so permitted.

Being bound together to a marked extent by the roots of vegetation, the soil is in this manner prevented from being cut or worn away by the rain.

(IV) INFLUENCE PRODUCED BY DENUDED FOREST AREAS.

(a) *Tendency of the removal of the forest cover to increase the amount of surface drainage and to decrease the amount of subterranean drainage.*

When a forest cover is removed, more of the rainfall reaches a lower level by running directly off the surface and less by sinking into the ground.

The rainfall is no longer able to sink readily into the ground along the trunks of the trees or the stalks of the underbrush. Moreover, no longer finding the soil loose and porous, but compact and hard, it now runs rapidly off the surface.

Besides this, the impact or blow of the rain drops hardens or compacts the soil, and this favoring the drawing up of water from below by capillarity, ensures a further loss by

evaporation at the surface, still further decreasing the amount of subterranean drainage.

(b) *Disturbances in the distribution of the drainage on the reservoirs of springs.*

The removal of the forest cover, tending as it does to decrease the amount of rain that reaches a lower level, by first sinking into the ground, necessarily causes a smaller quantity of water to reach the reservoirs of springs.

With the rapid drainage of the surface waters, and the consequent decrease of the underground drainage, the quantity of water reaching the reservoirs of springs is decreased and their flow necessarily lessened. Instead of being almost unaffected by dry weather their flow rapidly decreases on the approach of drought, and, after a time, may entirely disappear.

(c) *Effects produced by disturbances in the drainage on the quantity of water in the river channels.*

As the removal of the forest covering tends to increase the amount of rain that reaches a lower level by running directly off the surface almost immediately after a severe rainfall, the river channels must begin rapidly to fill, and soon to overflow and so cause floods.

The water that fails to reach the reservoirs of springs runs directly off the surface, and, instead of reaching the river channels by draining underground through the outlets of springs, runs directly into these channels and may thus cause disastrous floods.

(d) *Effects of the disturbance in the drainage, consequent on the removal of the forest cover, on the severity of droughts.*

The removal of the forest cover, tending as it does to decrease the amount of the rainfall that reaches the reservoirs of springs, causes the springs rapidly to dry up shortly after the rain ceases, and, consequently, tends to cause the rivers themselves to dry up, since they are no longer fed by the springs, and the surface water is no longer pouring into them.

The evils caused by too much water in the river channel almost immediately after the rain, are followed by those caused by too little water on the approach of drought. The

rivers completely or partially dry up and the springs fail. Vegetation is thus deprived of its liquid nourishment, the crops fail or the harvest is ruinously decreased both in quantity and quality.

(e) *Effects produced by the removal of the forest cover on the erosion of the surface.*

The removal of the forest cover and the consequent rapid surface drainage of the rainfall permits the removal of the soil, not only on account of the increase in the velocity with which the surface water flows towards a lower level, but also because the soil is now no longer held or cemented together by the roots of the vegetable growth. The soil in which the forests grew is thus lost to the area from which the trees were removed, and, unless such loss is trifling, must needs be replaced before a successful re-forestation or re-planting of the trees can be effected. Moreover, the influence, as far as the river channels are concerned, is not limited to the immediate neighborhood of the forest, but extends far beyond it.

(f) *Effects of the removal of the forest cover on the channels of the rivers whose basins lie in the areas so denuded.*

The soil removed from the river basins, both within the forest areas and in regions beyond these areas, is deposited in all parts of the river channel, where the velocity is sufficiently small, producing bars, mud flats, or shoals in the channel, or partially blocking the river's mouth by the well-known delta formation.

It is especially to be remarked that this influence reaches beyond the area of the forests, to wherever the river flows, viz., often from the mountains or cradles in which the streams are born, to their graves in a lake or ocean; or, not infrequently, from the interior of a continent to its ocean borders.

The damage thus wrought is, therefore, far-reaching: the uplands deprived of their soil, the lowlands are contaminated by the miasmatic and other noxious vapors passed into the air from the mud flats, and the navigation of larger streams is often seriously interfered with.

(V) INFLUENCE PRODUCED BY THE PRESENCE OR ABSENCE OF THE FOREST ON THE AMOUNT OF THE RAINFALL.

Since this must, to a certain extent, be regarded as one of the debatable questions in forestry, I would not attempt to discuss it in elementary teaching, except, perhaps, to state that the general concensus of opinion is that the presence of an extended wooded area appears in certain cases to increase somewhat the amount of the rainfall.

It might be well, however, in this connection, to point out the fact that the disturbances in the distribution or the rainfall which unquestionably attend the removal of the forests, are often confounded with disturbances in the quantity of the rainfall. Because destructive droughts and empty river channels follow in the wake of the removal of the forest, the unthinking are apt to ascribe such evils to a decreased rainfall, forgetting the floods in the same river channels which also attended the removal of the forests.

(VI) INFLUENCE PRODUCED BY THE PRESENCE OR ABSENCE OF THE FORESTS ON THE GENERAL CLIMATE OF THE EARTH.

This is also to be regarded as a yet unsettled question, and I would not, therefore, attempt to discuss it in elementary teaching.

I have given in the preceding synopsis of the effects produced both by the presence and by the removal of the forests, a short summary only of the general facts that I believe should be taught in such a discussion of forestry as I should recommend for teaching in our lower schools. Of course, there should be a development of the topics here only generally indicated. I have given this synopsis not only for forming the skeleton of a scheme for elementary study, but also for the purpose of convincing you that the character of the topics to be studied is far from being such as would elude the comprehension of young children. I think you will agree with me that these subjects, with perhaps a few exceptions, are of an exceedingly simple character, and such as could readily be taught. For my own part, I feel quite sure I could teach a class of ordinarily intelligent

children of any grade above the primary, sufficient of the preceding principles to enable them thoroughly to understand the good effects produced by the presence and the evil effects produced by the removal of the forests from extended areas.

As I have already stated, I would not recommend the use of a text-book in such study, unless it be a carefully prepared reader, which might be employed to great advantage. I would rather prepare both as an aid to the teacher and students a series of charts, each containing the outlines of a lesson suitable for the grade of the students employing it.

It is especially to be observed that much of the information required for such teaching of elementary forestry is of the nature of elementary geography, especially of that branch of geography generally known as physical geography. The study I recommend for introduction into the lower schools is not, therefore, properly to be regarded as a new study, but, as I have already remarked, it is rather an extension of geography or of elementary physical science.

Along with the preceding elementary principles relating to the effects produced by the presence or absence of forests, I would give elementary instruction concerning the best methods of re-forestation or tree planting.

The question of tree planting has properly been considered of such importance in this Commonwealth that two days are set aside as Arbor or Tree Planting Days, and I am glad to say that our school authorities have ordered that appropriate exercises shall be conducted in all the public schools on such occasions.

The subject of tree planting is naturally a very attractive one to intelligent children. So, too, is the growth of the tree, or, indeed, of any plant. In the first place, there is the germ or seed from which the tree grows. Then there is the cradle in which the plant after birth is nourished and cared for; such cradle is the soil. Then comes the sunshine and the heatshine that awaken the germ from its long sleep. Then comes the nourishment or food; first the part surrounding the germ and lying inside the seed, and next the greater part lying outside the seed, which the plant obtains from the

soil, or from the atmosphere. Such lessons can be made to the intelligent child more interesting than fairy stories; in fact, they form veritable fairy stories.

I would call the attention of the child to the different character of soils, and to the different ways in which soils are formed. I would show how, in most cases, the formation of soil was slow. How a portion of it, namely, the vegetable mould, was formed by an extremely gradual accumulation of the remains of decaying plants, pointing out how great a loss must ensue to any section of country if, by reason of the removal of its forests or other vegetable covering, the soil should be lost.

Having thus shown the effects both of the presence of the forest and of its removal, I would be especially careful to point out the many uses of the forest. I would show the extent to which the forest crop is necessary to man, especially teaching that man should be free to harvest the crop, explaining that the effort of intelligent forestry is not to prevent man from harvesting the forest crop, but to teach him how to do so intelligently, and how to replant denuded areas or properly to protect their surfaces if it be determined not to replant them.

Where time admits, the causes leading to the removal of the forests and the necessity that exists for such removal over very extended areas might next be discussed. Then, too, I would enumerate the various enemies of the forest; enemies from which the forests should be protected by the enactment of penal laws, viz., the greed of the lumberman, the forest fire, the ravages of winds or avalanches; the devastation by parasitic plants, insects and animals generally.

I have endeavored to show why I believe that the study of elementary forestry should be introduced into our schools in grades as low as the intermediate or grammar grades. I leave it to your judgment whether or not I have made out a good case for such introduction.

The History and Modern Development of the Art of Interchangeable Construction in Mechanism.*

By W. F. Durfee.

[*Concluded from p. 54.*]

The art of interchangeable construction was strongly reinforced by the discovery of the method of forging in dies. This idea was but an application of the art of coining cold metal for use as money (which had been known since the time of Darius, 500 years B. C.); to the shaping of metal while hot. The art of forging in dies is believed to have originated in France about the middle of the twelfth century; and numerous examples of "hinges," "grilles" and wrought-iron ornaments of various kinds remain as elegant testimonials of the cultivated taste and wonderful skill of these ancient artists in iron. Forged ornaments, shaped by "dies" (sometimes called "swages"), were common on all the pleasure carriages made in the last century, and it is certain that the wonderful "one-horse shay" would not have been the masterpiece it was if its "step-irons" had not been decorated with "swaged" ornaments.

It seems but a very short step, indeed, from the forging of ornamental iron work in dies, to the forging of the smaller parts of machinery in the same way; but as short as it undoubtedly was, it does not appear that it was taken until the late Albert Eames introduced the practise of forging parts of muskets and pistols in "dies" or "swages," at Chicopee, Mass., in 1842.

One more step forward in the art of forging the parts of interchangeable mechanisms brings us to what is known as "drop forging." This art is believed to be of American origin, and was first used at Harper's Ferry, Md., in the year 1827, in the works of J. H. Hall. An improved form of drop

* A paper read before the Mechanical Section of the Engineering Congress, at the World's Columbian Exposition (August, 1893).

forging machine was made by the late Albert Eames for the Remington Works at Ilion, N. Y., in 1846. From this date the use of the process of drop forging has rapidly increased, and it has been applied to the manufacture of very intricate as well as delicate articles. The Billings & Spencer Company, of Hartford, have for the past twenty-five years turned out annually large numbers of shuttles for sewing machines so nearly exact to size, as to require little work and polishing to render them fit for their intended service. The art of drop forging is also used for producing the heavier parts of bicycles and for an endless variety of forgings in iron, steel and copper; forging of the latter metal having come into use for electrical machinery within the last eight years. So important has the art of drop forging become as a factor in manufacturing, that at the present time no establishment for the manufacture of interchangeable mechanism, of which forgings are a component part, can afford to ignore its advantages. In the making of drop forging, the preparation of the dies is a matter of the first importance, and so high has American skill in this particular appreciated abroad, that from time to time, large numbers of finished dies have been sent from America to foreign countries. The Billings & Spencer Company, of Hartford, Conn., who are pioneers in the art of drop forging, shipped at one time forty-two tons of dies to Prussia, for the making of forgings for the parts of muskets.

The economical production of interchangeability in mechanism, necessitated instruments for rapid and accurate measurement. These were slowly supplied. The invention of the micrometer, by William Gasgoigne, of Yorkshire, England, about the year 1637, at once placed in the hands of science, the power of measuring to a degree of minuteness unknown before. Gasgoigne was killed when thirty-two years of age, at the Battle of Marston Moore, on the 2d of July, 1644, while fighting for his King. The principles of Gasgoine's micrometer consisted in moving two parallel edges or pointers, to or from each other, by means of a screw provided with a divided head. Dr. Robert Hook proposed to use in this micrometer parallel wires or hairs, but, with

such slow, hesitating steps did improvement move in the days of the youth of the micrometer, that it was not until 1755, more than 100 years after its birth, that the first suggestion of the use of spider webs therein was made by Prof. Felice Fontana, of Florence, and it was not until John Troughton's attention was called to the matter by David Rittenhouse, of Philadelphia, that it was carried into practice in 1788; the idea curiously enough reaching England by way of America. There is no certainty that Rittenhouse had ever heard of Professor Fontana's suggestion, but before calling Troughton's attention to the value of the spider lines for micrometers, he had already used them himself in the fixed diaphragm of a transit instrument. Since the application of the spider lines to the micrometer, this instrument has received endless modifications to adapt it to special service, from the hands of some of the ablest scientists and mechanicians of Europe and America. Neither my alloted time nor your patience will permit a description of what has been accomplished in the invention of special types of this instrument; but a brief account of the origin of the micrometer caliper, now so commonly used by the best workmen all over our land, may be of interest. It appears that the first of this form of caliper used in America, was made in the year 1867 in the machine shop of the Bridgeport Brass Company, at Bridgeport, Conn., from sketches furnished by S. R. Wilmot, who at that time was Superintendent of that company. This instrument was made to measure in thousandths of an inch, the thickness of sheet brass then being rolled for the Union Metallic Cartridge Company, to use for the manufacture of cartridges.

The requirements of the late A. C. Hobbs, then the Superintendent of the Cartridge Works, had so narrow limits of variation, that some more accurate means of measurement than the ordinary wire gauge was required to regulate the rolling. This is doubtless the first instance in which common-sense asserted itself successfully against several centuries of rolling mill practice, in determining the thickness of sheet metal, and it deserves to be regarded

as the initial step in the movement that promises ere long to consign all "*wire gauges*" to the tomb of defunct mechanical expedients.

It is also in evidence that a representative of the Brown & Sharpe Manufacturing Company, of Providence, R. I., saw at the Paris Exposition in 1867, an instrument of similar form and purpose, to that made by Mr. Wilmot, save that the French instrument had a revolving scale attached to its screw. This instrument was invented in *1848*, by Jean Laurent Palmer, a machinist of Paris; and was duly patented in France on the 7th of September of that year. The Brown & Sharpe Manufacturing Company commenced the manufacture of this form of "micrometer caliper" in the latter months of 1867, and from the time it was put on the market by them (1868), its use has rapidly extended; but, there is no small amount of humiliating interest in the fact that it was *nineteen years* after the publication of the invention of M. Palmer, in France, before the mechanics of America discovered the value of this very convenient tool.

The discovery by the late Sir Joseph Whitworth, of a way to produce plane surfaces on metal by "scraping," has had a marked influence in increasing the accuracy of work intended to be interchangeable, and so accurate have surfaces been made by the method described, in a paper read by him before the Institute of Mechanical Engineers, at Glasgow, in 1856, that it has been demonstrated that when two such surfaces are placed in contact, that it requires more force to separate them, than the equivalent of the pressure of the atmosphere upon them, thus showing that the surfaces were approaching the condition of actual molecular cohesion.

Thus far I have discoursed of the development of methods and apparatus which have rendered possible the art of interchangeable construction as it is understood to-day; and have had little to say of special industries whose products are representatives of the degree of perfection to which the art has attained.

When the idea of interchangeability was first promulgated, it was advocated with special reference to the manu-

facture of muskets, and it is a common belief that the idea of making the parts of muskets interchangeable originated in America, but the facts of history compel us to say that this view is not correct. Thomas Jefferson, writing from Paris, to John Jay, under date May 30, 1785, says: "An improvement is made here in the construction of muskets, which it may be interesting to Congress to know, should they at any time propose to procure any.

"It consists in the making of every part of them so exactly alike, that what belongs to any one, may be used for every other musket in the magazine.

"The Government here has examined and approved the method, and is establishing a large manufactory for the purpose of putting it into execution.

"As yet the inventor has only completed the lock of the musket on this plan: he will proceed immediately to have the barrel, stock, and other parts executed in the same way. Supposing it might be useful in the United States, I went to the workman. He presented me the parts of fifty locks, taken to pieces, and arranged in compartments. I put several together myself, taking pieces at hazard as they came to hand, and they fitted in the most perfect manner. The advantage of this when arms are out of repair are evident. He effects it by tools of his own contrivance, which, at the same time, abridge the work, so that he thinks he shall be able to furnish the musket two livres cheaper than the common price. But it will be two or three years before he will be able to furnish any quantity. I mention it now, as it may have an influence in the plan for furnishing our magazines with this arm."*

On the twenty-fourth of January, 1786, Mr. Jefferson writes a similar letter to the Governor of Virginia, in which he is even more emphatic in regard to the gun-locks, he has examined, saying that: "I found them to fit interchangeably in the most perfect manner."

In the year 1798 (thirteen years after Jefferson had found that gun-locks were manufactured in France which "inter-

* *The Writings of Thomas Jefferson.* Edited by H. A. Washington. 1853.

changed in the most perfect manner"), Eli Whitney, the inventor of the saw cotton-gin, contracted with the United States to furnish them with 10,000 stand of arms. In regard to this work, his biographer says,* "The object at which he aimed, and which he fully accomplished, was to make the same part of different muskets, as the locks, for example, as much like each other as the successive impressions of a copperplate engraving." This was a very high standard, and Mr. Whitney struggled energetically against all sorts of difficulties, and doubtless realized to some considerable degree, his intention of making the parts of the muskets interchangeable, and is entitled to great credit for the pioneer work in the art of interchangeable construction which he accomplished, and the large measure of success which he achieved in carrying out with the limited resources available in America at the time, the idea which Thomas Jefferson stated thirteen years before the date of Mr. Whitney's contract, was being prosecuted successfully in France.

Looking backward at the art of interchangeable construction as exemplified in the work done at the beginning of the century, and viewing it in the light of the exact requirements of to day, it is certain that very little of the work done at that time, would pass inspection now; most of the parts of the old muskets would doubtless interchange, but the exactness of the relations of the parts would not be found up to present standards. The demand for such precision was not made, and could not, with the means at command, have been realized if it had been insisted upon. Even the mechanical means of attaining interchangeability in some of the parts of muskets were not invented until 1853.

As a consequence of the pioneer work of Eli Whitney, and the enthusiastic zeal with which the path he blazed through unknown regions, has been followed, widened, and extended by multitudes of ingenious and skilful mechanicians. America has become the great school of the world for all who are seeking instruction in the art of interchangeable construction. As the result of the excellent work on a

* *Memoir of Eli Whitney, Esq.* By Denison Ohmstead. 1886.

small exhibit of rifles by Robins & Lawrence, of Windsor, Vt., at the International Exposition of 1851 in London, the British government sent a commission to America to study the methods of manufacture by which interchangeable construction was attained.

This commission visited Springfield Arsenal and a number of other public and private armories, and as a result they at once ordered a large quantity of American gun-making machinery, and secured the services of a number of American mechanicians to accompany it to England, and there established the Enfield rifle factory, the first in Europe, in which arms were made on the American interchangeable system.

As an illustration of the perfection which this system had attained when the English commission visited Springfield armory, in 1853, Major Ripley, who was then in command there, ordered ten guns manufactured from 1843 to 1853, to be taken apart, the parts indiscriminately mixed, and the ten guns were then successfully assembled by selecting the parts at random from the general mass.

Since the year 1853, American gun-making machinery has been supplied to the governments of England, Spain, Prussia, Sweden, Russia, Denmark and Egypt; and large quantities of American arms and ammunitions have been shipped to all quarters of the world. So manifest were the manifold advantages of the system of interchangeable construction, as applied to the manufacture of arms, that it has been extended to a great variety of other industries in which large numbers of the same kind of product are manufactured: Locks, sewing machines, steam valves, steam engines, hardware and agricultural implements, clocks and watches. The idea of manufacturing watches by the interchangeable plan is distinctly American, and was first carried into effect on a large scale at Waltham, Mass., in 1854. Since that date watch factories have increased and multiplied in the land and foreign nations have been compelled by American competition to adopt the idea which is the crowning triumph of the American system of interchangeable construction.

In the foregoing outline of the development of those

arts which are distinctly tributary to the art of interchangeable construction, I have endeavored to show that the idea of interchangeability in the construction of mechanism is of no recent origin: that, in fact, if not in name, the commencement of its practical development was coeval with the satisfaction of the most primitive of the artificial demands of man upon the materials of the world, in which he found himself placed: that as mankind increased, and multiplied his requirements of nature; the elements from which to create the art of interchangeable construction were necessarily augmented by the discovery of new methods and the invention of apparatus for their utilization: that this process of mental demand and material supply, changed gradually from the simple and easy, to the complex and difficult: but, nevertheless, every demand within what we have been irreverently taught to call the laws of nature, has been successfully met by the crystallization in its work of enough of the immortal soul of each succeeding generation, to enable the world of our day to enjoy the usufruct of the labors of all time past, and to rejoice in the practical perfection to which the art of interchangeable construction has attained.

Contemplating the magnitude of past achievements; realizing the vast power which the concentration of the inspired thought and best work of all ages have placed at our disposal, perceiving as "through a glass darkly" a suggestion of the manifold glories of that future which will be the living present of some unknown generation; we seem to see science in command of a grand ship called *Art*, fully rigged, manned and equipped for a voyage of unknown length; its prow pointed westward, as, with adventurous keel, flowing sails, and a crowning glory of flags, pennons and streamers, it speeds over the uncharted waters of the ocean of time towards undiscovered shores. As we view the picture and reflect upon the persistent faith that has guided the noble vessel to the discovery of fair islands and grand continents in time past—the mind naturally reverts to the voyage of that great discoverer, in whose name we have erected these temples, and invited all lands to do him

honor by offerings of gold and silver, frankincense and myrrh.

It is by such persistence as his, in following the directing compass of an o'er mastering faith, that science and its argosy will make discoveries of new lands under skies and stars to us unknown. On such a voyage science will permit of art no suggestion of turning, and when doubt shakes its skeptical head, and fear asks timorous questions, the reply of science will be as sternly decisive as was that of Columbus, when

> " Behind him lay the gray Azores,
> Behind, the gates of Hercules,
> Before him only ghosts of shores;
> Before him only shoreless seas,
> The good mate said: 'What shall I say
> If we sight naught but seas at dawn,'
> Why you shall say at break of day?
> 'Sail on—sail on—sail on—and on.' "*

COMMENTS ON THE DETERMINATION OF PHOSPHORIC ACID BY TITRATION OF THE "YELLOW PRECIPITATE" AS DESCRIBED BY MR. HENRY PEMBERTON, JR.

By W. J. Williams, F.I.C., F.C.S., etc.

[*Read at the stated meeting of the Section, held November 21, 1893.*]

On September 19, 1893, at a meeting of the Chemical Section of the Franklin Institute, I heard with great interest Mr. Henry Pemberton's, Jr., paper on the determination of phosphoric acid by titration of the yellow precipitate with standard alkali.

For some time I have been seeking a *reliable* volumetric method for the determination of phosphoric acid. The well-known uranium nitrate method is sufficiently accurate for most purposes on an aqueous solution of phosphoric acid, but is entirely unreliable if the phosphatic material is dissolved in mineral acids or even in acetic acid.

* Joaquin Miller.

After some conversation with Mr. Pemberton on the subject, subsequent to hearing his paper, he very kindly sent me by letter some valuable hints and instructions on the details of the process, with the help of which I began my investigation.

The first trials were made on ordinary mixed fertilizers, containing ammoniates and potash salts, and the result showed an almost exact agreement with previous results obtained by the usual gravimetric method.

	Phosphoric Acid by Pemberton's Vol. Method. Per Cent.	*Phosphoric Acid by Gravimetric Method. Per Cent.*	*Difference Per Cent.*
Ammoniated phosphate, ...	15·475	15·480	0·005
Acid phosphate with ammonia and potash,	13·175	12·980	0·195
Acid phosphate with ammonia and potash,	13·730	13·820	0·090
Acid phosphate with ammonia and potash,	11·100	11·000	0·100

These I consider to be highly satisfactory results, and such as justified further investigation as to the reliability of the method on substances rich in phosphoric acid, such as Florida phosphate rocks, and on the other extreme of substances low in phosphoric acid, such as the "insolubles" in a well-made fertilizer.

High-grade Acid Phosphate.—Working on 0·2 gram for the "total phosphoric acid," and on 0·5 gram for the phosphoric acid "insoluble in ammonium citrate," I found

	By Volumetric Method.	*By Gravimetric.*	*Difference.*
"Total" No. 1, ...	16·830	16·57	0·26
No. 2, ...	16·750	16·89	0·14
"Insolubles" No. 1, ...	0·24	0·32	0·08
No. 2, ...	0·36	0·32	0·04

On ordinary mixed fertilizers.—

"Totals" No. 1, ...	15·28	14·78	0·50
No. 2, ...	14·60	14·14	0·46
No. 3, ...	12·29	11·45	0·84
No. 4, ...	13·83	13·43	0·40
"Insolubles" No. 1, ...	1·90	1·79	0·11
No. 2, ...	4·35	4·22	0·13
No. 3, ...	2·06	2·17	0·11
No. 4, ...	1·82	1·79	0·03

Here, again, I consider the results highly satisfactory.

I next worked on high grade Florida phosphate rocks, using in each case 0·1 gram of substance. To insure a fair sample, however, I first dissolved five grams of rocks in hydrochloric acid, and made up to 250 cubic centimeters and mixed thoroughly by shaking and decantation. Of this solution I took fifty cubic centimeters equal to one gram of rock, diluted to 250 cubic centimeters, and again mixed thoroughly by shaking and decantation. I then took twenty-five cubic centimeters of this second dilution equal to 0·1 gram rock, brought it to alkalinity with ammonia, and acidified with nitric acid, adding a little ammonium nitrate.

	By Volumetric Method.	*By Gravimetric.*	*Difference.*
Florida rock No. 1, ...	32·33	33·00	0·67
No. 2, ...	30·66	30·89	0 29
No. 3, ...	31·55	31·54	0·01
No. 4, ...	31·37	31·34	0·03
No. 5, ...	33·17	33·33	0·16
No. 6, ...	33·24	33·14	0·10

The greatest variation is in No. 1, where it reaches 0·67 per cent., but this is small compared with the variation in results from different analysts. For instance, No. 3 was analyzed by four chemists of repute, and the results were 31·54 per cent., 31·61 per cent., 31·86 per cent. and 34·56 per cent. The chemist who reported 34·56 per cent. was requested to revise his figures and reported the second time 34·44 per cent. These show a greater divergence from the results of the three first analysts than is found in the case of No. 1.

I think, therefore, that Mr. Pemberton's method followed carefully according to his instructions is entirely reliable, for high grade rocks, for plain acid phosphates and for mixed fertilizers, in the hands of careful and competent analysts. But with careless or unskilful manipulation the chances of serious error are very great. For instance, incomplete washing of the yellow precipitate would lead to very serious errors and misleading results but in careful hands the method is accurate and reliable.

WILMINGTON, DEL., November 21, 1893.

COMPARISON OF PEMBERTON'S METHOD OF PHOSPHORIC ACID DETERMINATION WITH THE OFFICIAL METHOD.

BY FRANCIS BERGAMI.

[*Read at the stated meeting of the Chemical Section, December 19, 1893.*]

By the kindness of Dr. Terne, I came into the possession of a copy of Mr. Pemberton's paper, on "Phosphoric Acid Determination." The results shown therein indicate such a surprising accuracy of the method that Dr. Terne requested me to start an investigation at once, as it would be of the highest importance in our work to find a more rapid (and at the same time, equally accurate) process of phosphoric acid determination than the official method. As my spare time is very limited, I have extended my tests only to such materials as just at present enter our laboratory for examination. These materials consist mostly of ammoniated and mixed phosphates.

The results of all the tests made up to this time are given in the following table:

PHOSPHORIC ACID.

SAMPLE.	Official Method.	Pemberton Method.	Difference.
(1) Ammoniated phosphate,	11·84	11·68	0·16
	—	11·77	0·07
(2) Ammoniated phosphate,	13·20	13·05	0·15
	—	13·14	0·06
(3) Ammoniated phosphate,	8·80	8·68	0·12
(4) Ammoniated phosphate,	8·74	8·74	—
(5) Dissolved bone-black,	20·68	20·56	0·12
(6) { Ammoniated phosphate,	—	10·93	0·03
{ Water-soluble, phosphoric acid,	10·96	10·84	0·12
(7) Ammoniated phosphate,	12·48	12·35	0·13
(8) Dissolved bone-black, not identical with No. 5,	20·68	20·55	0·13
(9) Acidulated S. C. Rock:			
Total phosphoric acid,	15·52	15·34	0·18
Insoluble phosphoric acid,	1·72	1·68	0·04
Available phosphoric acid,	13·80	13·66	0·14
(10) Ammoniated phosphate,	12·32	12·17	0·15
(11) { Ammoniated phosphate,	—	—	—
{ Water-soluble, phosphoric acid,	10·56	10·47	0·09
(12) Acidulated S. C. Rock:			
Total phosphoric acid,	15·29	15·16	0·13
Insoluble phosphoric acid,	2·56	2·49	0·07
Available phosphoric acid,	12·73	12·67	0·06
(13) Refuse bone-black,	34·40	34·03	0·37
	—	33·94	0·46
	—	34·03	0·37
(14) South Carolina rock,	27·66	27·34	0·32
(15) Florida rock,	32·24	31·94	0·30

In reviewing all the results, it can be seen that, on the average, the Pemberton process gives slightly lower results than the official method. Assuming my work to be as free from individual error as careful work can be, there are only two explanations for the differences: either the results of the official method are a little too high, or those of the Pemberton method are a little too low. I feel very much inclined to accept the first explanation, for the following reason:

It has been repeatedly stated by different chemists that it is hardly possible to obtain by one precipitation a precipitate of ammonium-magnesium phosphate absolutely free from magnesium oxide, and it has been recommended to dissolve the precipitate again and re-precipitate it with ammonia.

Dr. N. von Lorenz has only lately published his investigation in regard to this source of error in the official method (*Fresenius Zeitschrift*, 1893, p. 64). He shows that addition of about two per cent. of citric acid to the solution of the phosphomolybdate in ammonia will prevent any contamination by magnesium oxide.

When I had obtained the results on Sample No. 13, a refuse bone-black, I found the difference between the official test and even the highest result of the Pemberton method, namely, 0·37 per cent., too high to be passed without a closer consideration. In this case, I had accidentally omitted the neutralization of the ammoniacal solution of the phosphomolybdate by hydrochloric acid. Therefore, the idea struck me that this neglect might be the cause of the too high result, and I concluded to repeat the test twice with addition of citric acid, as recommended by Dr. von Lorenz.

The results thus obtained were 34·08 per cent. and 34·16 per cent. against 34·03 per cent. and 33·94 per cent. by Pemberton method and 34·40 per cent. by official method without neutralization. In former years, I had always precipitated without previous neutralization of the ammonia solution, but as I have lately followed strictly the official way and neutralized, I thought surely that the omission of

neutralization was the cause of the high result. The smaller differences in all previous tests could easily be explained as individual working errors, but when I obtained the results in Samples 14 and 15, I was a little astonished.

In these cases, I was sure of no neglect on my side; the official way was carefully carried out as in all other samples, and I had made the solutions of the yellow precipitate as nearly neutral as possible. Still, the differences between both methods were 0·30 per cent. and 0·32 per cent., respectively.

I always wash the ammonium-magnesium phosphate until the filtrate shows no chlorine reaction, so that the source of error arising from incomplete washing is absolutely excluded, and I am, therefore, at a loss to find any other explanation for the differences than that, even in nearly neutralized solutions, a small amount of magnesium oxide is thrown down, together with the ammonium-magnesium phosphate, and renders the results of the official method too high. Naturally, the error will show itself more in high-grade phosphates than in those of lower percentage.

In calculating the results, I used the figures obtained by Mr. Pemberton, which are based upon the fact that twenty-three molecules of alkali are necessary to neutralize one molecule of ammonium phosphomolybdate. In establishing this fact, Mr. Pemberton precipitates a solution of di-sodic hydric phosphate by magnesium mixture, but he obtains a precipitate absolutely free from magnesium oxide by taking the precaution to dissolve the first precipitate again and re-precipitate with ammonia.

In this way he eliminates the above-stated error in the official method.

If, in establishing the relation between the phosphoric acid in the yellow precipitate and the standard alkali solution, the ammonium-magnesium phosphate were weighed directly after the first precipitation, I feel almost sure the figures thus obtained would be higher, and that results in analyses calculated on those figures would not show such large differences from the official method, as they would involve the same source of error.

In regard to the execution of the Pemberton method, I should like to state the following:

Extremely great care must be taken in washing the yellow precipitate until free from acid. Testing with delicate litmus paper should never be omitted. In regard to rapidity, I found it of some advantage to introduce a little change in Mr. Pemberton's mode of procedure.

To the twenty-five cubic centimeters of acid solution, which is always obtained in the same way (one grain substance thirty-five cubic centimeters nitric acid and five cubic centimeters of hydrochloric acid), I add at once ten cubic centimeters of strong ammonia (specific gravity 0·90), and, after a little stirring, fifteen cubic centimeters of nitric acid (specific gravity 1·42).

This operation secures about the same conditions for all tests, and produces at the same time a temperature of 75° to 80° C., which reduces the time required for heating to boiling point to a minimum.

The method is absolutely free from all difficult manipulations, and the only inconvenience I experienced with it occurred in such samples as gave dark colored acid solutions.

A considerable part of the coloring matter enters the precipitate and imparts to the solution in alkali a brownish color.

This renders the titration a little difficult, and may, in some cases, give rise to uncertainty and error. A previous ignition of the sample or treating with concentrated sulphuric acid would overcome this difficulty. Whether in the case of solution in sulphuric acid, a larger amount of nitrate of ammonia and a longer allowance of time for complete precipitation would be necessary, is still an open question and needs investigation.

Mr. Pemberton recommends a standard alkali solution, which is free from carbonic acid. I have found that in the determination of nitrogen and ammonia a solution with a small amount of carbonates works just as well, as if free from the same, provided phenolphthalein and cochineal are used as indicators for standardization and analysis,

respectively. Both indicators show absolutely sharp end reactions, even if a small amount of carbonates is present. Curious of seeing if carbonic acid would have any detrimental effect in this special case, I repeated some of the tests with an old soda solution, containing some carbonates, with the following results:

Sample.	*1*	*4*	*5*	*12*	*15*
Alkali with CO_2, ...	11·68	8·69	20·47	15·07	31·94
Alkali without CO_2, ...	11·77 11·68	8·74	20·56	15·16	31·94

The close agreement of the different results seems to show that the precipitation of the carbonic acid is an unnecessary precaution.

I do not consider the number of tests made sufficient to prove the absolute infallibility of the Pemberton method, but I think that my work shows at least the probability of obtaining fair results by the same.

The results obtained by Mr. Pemberton and myself should be encouraging enough for any chemist employed in the control of fertilizers, to make a careful study of the method, with the hope of producing an absolute proof of accuracy, which would justify the abandonment of the old, tedious and time-wasting procedure of the official method.

NORMAL CHLORINE IN SPRING WATERS NEAR PHILADELPHIA.

By Reuben Haines.

[*Read at the stated meeting of the Section, held December 19, 1893.*]

The term "normal chlorine" is used to designate the amount of chlorine naturally existing in waters that are entirely free from all contaminating influences arising from the life and occupations of man.

Not only are waters directly polluted by this means to be excluded, but also those in which the ground water within their drainage areas has been contaminated. It is necessary, therefore, to obtain the water from near its source and to ascertain that within its watershed there exists nothing likely to affect the chemical character of the water. In a very sparsely inhabited region comprising large tracts of forests and uncultivated land such normal waters would not be difficult to find. It is quite otherwise in fertile agricultural districts in the vicinity of cities and towns.

It appears probable that in most instances the natural or normal chlorine of a particular locality will be found a tolerably constant average, although wide variations are found occasionally in single cases. This has been found true in Massachusetts, where this matter has been under investigation for several years.

As chlorine is one of the most important factors in water analysis for determining the potability of a water and, by reason of its permanence in the form of sodium chloride, is well adapted for the relative measurement of pollution, it is desirable to know the amount which is normal for a particular locality.

It should be stated, however, that the question of potability is not necessarily considered in the selection of these normal waters. Thus many swamp waters although very highly colored and containing large amounts of vegetable matter are quite suitable for this purpose. While on the other hand many spring waters which receive ground water

draining from farm-land are sufficiently pure for domestic use, but are for this reason, viz:—the character of the ground water—not to be classed as normal waters.

Special geological features of rock or soil, however, may greatly affect the chlorine content of waters in certain districts so far as to render the determination of chlorine of little value for this purpose. In the vicinity of the sea-coast a considerable increase in chlorine is to be expected, which, except in immediate proximity to salt marshes and within the line of highest tides, is probably due to salt spray carried inland by winds and precipitated with the rain.

Investigations in Massachusetts (*Report of State Board of Health on Examination of Water Supplies and Inland Waters*, 1890) have shown that the normal chlorine decreases in quite regular series from the coast to the central part of the State. Normal waters near the coast contain about 0·65 part chlorine per 100,000, and in the western part of the State less than 0·10 part. Lines called "isochlors" are drawn on a map of the State, connecting localities having equal amounts of normal chlorine, and these "isochlors" have a general parallelism to the coast line. It appears reasonable to attribute the gradual decrease of normal chlorine to the diminishing influence of sea-air.

From some recent investigations I have made, I believe, a somewhat similar series for normal chlorine can be found for New Jersey and Eastern Pennsylvania. In the present paper, the vicinity of Philadelphia, west of the Delaware River, is alone under consideration. It has, however, been quite difficult to find sources of water in this district which would reasonably satisfy the necessary conditions. Springs on a wooded hillside were mostly selected.

Ten springs, of which twenty-one samples were taken at different times during the year 1893, were found to be available for the purpose and were distributed as follows:

Five springs located on or near the line of the Philadelphia and Newtown Railroad, of which eight samples were taken. Four springs in Chester County, of which there were six samples. One spring on the Wissahickon Creek, Fairmount Park, seven samples taken almost monthly, from April to October.

The results are given as follows, stated in parts per 100,000:

NEWTOWN RAILROAD FROM HARPER'S TO PAPER MILL STATION.

Number of Spring.	*I.*	*II.*	*III.*	*IV.*	*V.*
First sample, ...	·27	·26	·24	·27	·23
Second sample, ...	—	·283	·245	·256	—
Average, ...	·27	·271	·242	·263	·23

CHESTER COUNTY, PA.

Location.	*Cedar Hollow.*	*White Horse Road.*	*Daylesford.*	*Malvern.*
First sample, ...	·210	·190	·170	·240
Second sample, ...	·180	—	·256	—*
Average, ...	·195	·190	·213	·240

* A second sample of this spring, taken five months after the first, was rejected, because a large increase in nitrates, as well as increase in chlorine, showed some pollution to have taken place between these periods. The amount of nitrates in the first sample, collected May 30th, was ·072 parts per 100,000.

WISSAHICKON PARK DRIVE, SPRING ABOUT 400 YARDS ABOVE RITTENHOUSE LANE.

Seven samples collected from April 12 to October 9, 1893:

Number of Sample.	*I.*	*II.*	*III.*	*IV.*	*V.*	*VI.*	*VII.*
Chlorine, . . .	·16	·15	·22	·22	·214	·183	·207

Average of these seven samples, ... ·193

In four of these samples the nitrates were determined, giving a maximum of ·10, minimum ·08 and average ·087 parts per 100,000. A determination of ammonia gave no free ammonia and an exceedingly small amount of albuminoid ammonia.

The average chlorine for the series is ·231 parts per 100,000.

It is probable that the results from the spring at Cedar Hollow and the one on the Wissahickon represent most nearly the true normal, since three of the others are possibly influenced by the cultivation of land or by pasturage in their vicinity. The spring at Cedar Hollow gave only faint traces of nitrates in 100 cubic centimeters of water. The condition and environment of this spring were very good. It flows rapidly from the base of a steep hill covered with dense

woods. Of the springs near the Newtown Railroad, the second gave nitrogen in the form of nitrates ·05 parts per 100,000, and the fifth no nitrates.

It is probable, therefore, that the normal chlorine for the vicinity of Philadelphia approximates closely to ·20 parts per 100,000, and presumably rather under than over this amount. Additional analysis of these and other springs are desirable in order to fix the limit more definitely.

The chlorine was determined by the usual volumetric method with silver nitrate and potassium chromate, but with the improvements and corrections described by Hazen (*Amer. Chem. Jour.*, xi, 409). As this improved method may not be familiar, except to those making similar investigations, it may be briefly stated here as follows: 200–250 cubic centimeters of the water to which are added fifteen to twenty milligrams sodium carbonate are evaporated in a porcelain dish to about twenty-five cubic centimeters. Wash down sides of dish with distilled water, using a rubber, until the volume approximates fifty cubic centimeters. When cold, add one cubic centimeter potassium chromate solution containing sixty milligrams chromate per cubic centimeter. Titrate with silver solution equivalent to 0·5 milligram chlorine per cubic centimeter until a faint permanent tint is visible. From the result of titration deduct a correction for volume represented by the formula

$$X = \cdot 003\ V + \cdot 02$$

in which V is the volume of the liquid in cubic centimeters at the end of the titration. The silver nitrate solution is also corrected previously in making up the solution by the addition of one per cent. of the theoretical weight of silver nitrate required; or standardize with sodium chloride solution and apply the above correction for volume, which will give the same strength of solution. In colored waters from swamps or peaty waters the coloring matter is, previously to evaporation precipitated by alumina hydrate, or by aluminum sulphate and sodium carbonate. The solid residue in a platinum dish after ignition by Drown's radiator may also be used for the determination of chlorine, if pre-

vious to evaporation, fifteen to twenty milligrams of sodium carbonate have been added to the water. I have found duplicates to agree very exactly when using this residue after ignition and have found close agreement between all three methods of getting rid of the vegetable coloring matter in natural waters, as described by Hazen. When using aluminum sulphate it is best to perform the titration with silver nitrate by gaslight.

A CONTRIBUTION TO PEMBERTON'S VOLUMETRIC METHOD FOR PHOSPHORIC ACID DETERMINATION.

By Dr Bruno Terne.

[*Read at the stated meeting of the Section, held December 19, 1893.*]

On September 19, 1893, Mr. Henry Pemberton, Jr., presented to the Section, a paper on the "Determination of Phosphoric Acid by the Filtration of the Yellow Precipitate with Standard Alkali."

The results obtained by Mr. Pemberton were such, that it appeared to us, at once, the results of this investigation should be taken up by the chemists interested in the determination of phosphoric acid.

At my request, Mr. Francis Bergami, for the last seven years in charge of the analytical control work of the factory of the Baugh & Sons Company, undertook to make a comparison of the Pemberton method with the official gravimetric method.

Mr. Bergami has made such comparison in fifteen different samples. The first twelve samples represent market products of the fertilizer trade; the last three samples, of raw material for the manufacture of the first.

The highest difference between the two methods, in the first twelve samples, is 0·16 per cent.

If you take up my paper read before the Section, October 18, 1892, pp. 9 to 12, and compare the differences which the official chemists have made on the test sample, you will find

that the differences between the official and the Pemberton method, as obtained by Mr. Bergami, are insignificant.

In the last report issued by the Agricultural Department, of the meeting held in Chicago, August 24 to 26, 1893 (*Bulletin* 38), we find on p. 8, determinations of citrate-insoluble phosphoric acid made by seventeen different chemists, with results of :

Highest. *Per Cent.*	*Lowest.* *Per Cent.*	*Differences.* *Per Cent.*
1·69	1·33	0·36
2·11	1·03	1·08

while Mr. Bergami, in Samples 9 and 12 in the citrate-insoluble phosphoric acid between the official and the Pemberton method, found only differences of 0·04 and 0·07 per cent.

Taking the results of the last three samples with high percentage of phosphoric acid, the highest difference obtained between the two methods, is 0·46 per cent.

Compare this, with the results of the test samples in 1892 for total phosphoric acid by the official method, and you find recorded 0·46 per cent., 1·28 per cent., 1·50 per cent., 1·45 per cent.

While the Samples 13, 14 and 15 of Mr. Bergami show, as the highest, 0·46 per cent., the last official record we have on total phosphoric acid, gives the same figure, as the lowest difference.

The volumetric method, as proposed by Mr. Pemberton, is, in my judgment, as reliable as the official method, and, if anything, more correct in the results.

A great advantage for a laboratory, is the time-saving of this method, without any loss of accuracy.

The work, that Mr. Bergami lays before you has been done with the utmost care and critical observation of all possible shortcomings of the new method.

I am so satisfied with the results obtained, that I do not hesitate a moment to adopt the Pemberton volumetric method for the control of our factory work, though samples of shipments must be treated according to the adopted rules of the association.

This volumetric method of determining phosphoric acid is, to my mind, of such value to all chemists interested

in phosphoric acid determination, and principally to the station chemists and fertilizer manufacturers, that a united effort should be made to push the adoption of the same, at least as an alternate method, before the Association of Official Agricultural Chemists.

I know that Mr. Williams, of Walton Whann & Co., at the next meeting, as indicated in the communication he sent to the Section, will join in this movement.

I shall endeavor to bring this matter prominently before the next meeting of the association, and in the meantime I am trying to interest the leading members of the association in the very excellent method of our fellow-member, Mr. Pemberton.

THE THEORY AND DESIGN OF THE CLOSED-COIL CONSTANT CURRENT DYNAMO.

BY HENRY S. CARHART.

[*A lecture delivered before the Electrical Section, December 26, 1893.*]

Constant current dynamos for arc lighting have been in practical use for the past fifteen years. Most of the public lighting by arc light service has been done with dynamos of the open-coil type. They secured the field at an early day in the development of this branch of electrical industry through the inventive genius of Mr. Charles F. Brush and the splendid ability of his business associates. This success was repeated a little later by the equally brilliant achievements of Professors Thomson and Houston and the phenomenal management of the company formed to exploit their patents. Aside from any question of inferiority, it is therefore easy to see why the closed-coil dynamo for constant currents has remained so long in the background. It has not received the attention to which it is justly entitled, and has not been investigated with the thoroughness and skill which it merits. It is not my purpose to draw any comparisons whatever between open- and closed-coil armatures. The former is entitled to that consideration which long-con-

tinued and satisfactory service in public and private illumination has earned for it. But the latter is making its way into public favor, and it has certain peculiarities which make it an interesting subject for study. If I were to draw attention in this paper to comparisons between dynamos of different types, it would be between those for constant potential and those designed for constant current, both with closed-coil armatures. For in almost every particular the latter is diametrically opposite to the former. The one is designed to give a constant potential; the other a constant current. One is shunt or compound wound; the other series wound. In the one the resistance of the armature is as low as possible in comparison with the field; in the other the armature resistance is relatively large compared with the field. The one has a sensitive field and is worked below the saturation point; the other should have a stable field which is worked well up on the saturation part of the curve of magnetization. Ideally the characteristic of the one is a horizontal line; that of the other a vertical line. In the constant potential machine the brushes are set only slightly in advance of the theoretical neutral line or plane; in the constant current dynamo the brushes may be at any point on the commutator according to the load, while the neutral plane remains fixed. When the load decreases with the one the brushes if moved at all are rocked backward for sparkless commutation; when the load decreases with the other the brushes are rocked forward for minimum sparking or even sparkless commutation and constancy of current. When the load increases on the one it governs by an increase of induction from an increasing field; when the load increases on the other it governs by decreasing the counter electro-motive force in the coils between the brushes and the neutral plane. In the one armature reaction is purposely reduced to the smallest dimensions; in the other it is purposely made of considerable dimensions. In these comparisons it is assumed that the speed is constant in both cases. If some of these statements are not self-evident, they will be supported, I hope, by subsequent portions of this paper.

THE NEUTRAL PLANE INDEPENDENT OF THE PLANE OF COMMUTATION.

By neutral plane is meant a plane passing through the axis of the armature and so situated with reference to the poles of the field magnet, that when a coil of the revolving armature is carried across it the electro-motive force generated changes direction. This plane intersects the armature in a straight line, but it may broaden out more or less into a surface of small lateral dimensions.

The plane of commutation is a plane passing through the armature axis and the points of contact of the brushes on the commutator. It is the plane joining the poles of the armature considered as an electro-magnet. This latter plane of course shifts with the brushes, since the poles of the armature are the points at which the current enters and leaves the armature, and these are necessarily the points or surfaces of contact of the brushes with the commutator, assuming that the connections from the armature to the commutator run directly out parallel to the shaft. To state the proposition now under discussion in the form of a question, does the neutral plane shift when the brushes are shifted forward or backward? If we were to make answer from the assumption that the resultant of two impressed magnetizations or magneto-motive forces may be obtained in the same manner as the resultant of two forces by means of the triangle of forces, we should probably conclude that the neutral plane rotates forward with a forward movement of the brushes. But experiment along several different lines shows that this conclusion is in error. If we were to apply to the solution of this problem the principles derived from constant potential machines we should be forced to the conclusion that, to maintain sparkless commutation at the brushes, the lead of the brushes beyond the neutral plane should be constant, since the current remains constant; and therefore that any attempt to govern for constant current by rocking the brushes must be attended by destructive sparking, unless at the same time the field is greatly modified. But these conclusions are also erroneous.

We must therefore first establish the facts and then make a theory to fit them.

The fixed position of the neutral plane I have determined on a ten-light machine in two different ways.

First Method.—Four turns of No. 16 silk-covered magnet wire were wound around the armature ring as an exploring coil. One end of this coil was soldered to a copper band or ring fastened on the commutator and insulated from it by several thicknesses of mica. The other end was soldered to a piece of brass let into a fibre collar placed round the commutator. One extra brush was fastened to one of the main brush holders and rested on the copper band. The other extra brush rested on the fibre collar and could be attached to any point of a circular scale made concentric with the commutator. A twisted cord ran from these two brushes to a telephone at some distance. When the dynamo was running the movable brush, which rested on the fibre and made contact with the brass strip every revolution, was moved round the circle till a minimum sound was heard in the telephone. The exploring coil was then on the neutral plane at the instant when the brush made contact with the strip. Motion of the brush either way caused the sound to increase in loudness. The position of the exploring coil for minimum sound was found to be about 5° in advance of the normal plane intermediate between the pole pieces; and its position did not change from full load to no load as far as could be detected by this method.

Second Method.—To the brush holders was attached an insulating ring slotted on the periphery at every 10° on a milling machine. It was made as nearly concentric with the commutator as possible. A third brush holder was placed in the successive slots, and the potential difference between it and one main brush was measured in its several positions. These measurements gave the integrated potential difference between the main brush and successive points on the commutator all the way round the circle and back to the starting point. This was done with no load or nearly short-circuit, with a load equivalent to three lamps,

and finally with a load equivalent to nine lamps, the current being ten ampères in each case. The results in the first two cases are plotted round a circle in *Fig. 1*. Positive values, or those in which the potential of the third brush was higher than that of the main positive brush, are set off outside the circle in the upper part of the figure; while nega-

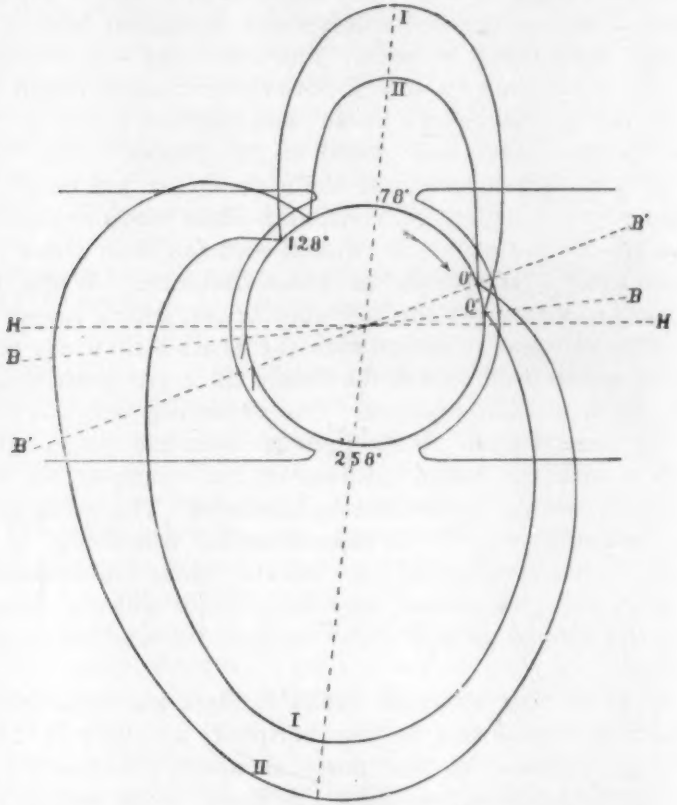


FIG. 1.

tive values are set off outside in the lower section of the diagram. The direction of rotation is clockwise. With no load the highest positive potential was about 78° behind the positive brush. From this point it fell again, and at 128° it was the same as that of the positive brush. For all the coils between 0° and 128° the integrated positive and

negative electro-motive forces exactly equal each other. The neutral plane falls evidently 78° behind the brush, or the brushes may be said to have a lead of 78°, with no increase in sparking. A negative maximum occurred at about 260°, and the potential difference between the positive and negative maxima was 644 volts. The same potential difference was found by direct measurement when two extra brushes were set at these points.

With a load equivalent to three lamps the brushes were rocked back 15° to bring the current to ten ampères. Hence, the zero of this curve begins 15° back from the zero of the first curve. Again, the observations are plotted and the positive maximum falls at the same place on the circle, and, therefore, at the same place on the commutator. The two maximum points are at about 65° and 245° from the positive brush and the two potential differences are 168 and 456 volts. Their sum this time is 624 volts, a little less than with no load. With the highest load carried the brushes were rocked backward about 50° further and the lead was then about 15°. The extreme potential difference obtainable this time did not exceed 600 volts. So far as can be discovered from these curves the neutral plane remains fixed, while the brushes move round the commutator to adjust to a constant current. I find no evidence in them that the forward movement of the brushes to control the current causes the neutral plane to move with them. As the brushes advance with a diminishing external load they put between them and the neutral plane an increasing number of armature-turns, generating counter electro-motive force; and it is a striking fact that, when the field coils are not cut out, the back-turns on the armature cut down the potential difference between the brushes, not by a counter magneto-motive force apparently, but by counter electro-motive force; for the maximum potential difference to be found on the commutator is no less on no load than on full load, showing that at least as many lines of force traverse the armature core with the brushes far forward and with many back armature-turns as with the brushes in

the position for maximum load and with the back-turns reduced to a minimum.

THREE METHODS OF GOVERNING.

Assuming still practically constant speed, we next inquire into the methods employed to maintain a constant current without appreciable sparking by rocking the brushes round the commutator cylinder.

In one machine the brushes are moved automatically by means of a small electric motor and at the same time field coils are successively cut out as the brushes rock forward with a light load. A pair of brushes is used on each side and they are kept at a fixed distance apart. By these combined means the machine can be run on short-circuit with the normal current and without sparking.

Another system leaves the field coils constantly in circuit, but employs two pairs of brushes and varies the angular distance between the members of each pair when the brushes are moved. The movement of the brushes is effected mechanically in response to any change in the main current till the current is brought back to the normal value. In these machines the spread of each pair of brushes, or what is sometimes called the overlap of the brushes, is lessened as they rock forward toward the polar centres. Very satisfactory results are secured in this way.

In the third class of machines only one pair of brushes is used, which lap over about two or three commutator sections, and the regulation of the current is effected solely by the movement of this one pair without change of overlap and without disturbance of the ampère-turns on the field. The brushes are moved mechanically by means of an automatic regulating device. No less satisfactory results appear to be secured by this method than by the others, while the mechanism as a whole is somewhat simpler.

I have described these three methods for the purpose of pointing out their bearing on the theory and design of closed-coil Gramme rings for constant currents. The important question is not how to get the necessary electro-motive force with such a dynamo, but how to vary that electro-

motive force in response to the varying demands of the external circuit, without injurious sparking at the brushes.

The electro-motive force is controlled in all three of these methods by rocking the brushes, the other differences in the devices are made necessary for the suppression of the sparking. This brings us to a consideration of the most intrinsically interesting topic of the paper, viz: the conditions necessary to suppress sparking and the features of design required to furnish them.

SUPPRESSION OF SPARKING.

If we assume that the armature is well balanced electrically and magnetically, and that the brushes have a proper bearing in contact with a smooth commutator, the conditions required to commute the current without sparking are known to be as follows: With a two-pole dynamo, the current is divided through the armature, one-half going from brush to brush through one side, and the other half through the other. Hence, when an armature coil is carried past the brush it is transferred from the one circuit through the armature to the other, and at the same time the current through it reverses its direction. This constitutes the act of commutation. But the sudden decay of a current through a coil in one direction and its growth to an equal value in the other gives rise to an electro-motive force of self-induction opposing the change. This electro-motive force will prolong the flow of the current on one side of the brush and will oppose its rise on the other side. Hence, if the coil is short-circuited by the brush lapping over the two consecutive commutator segments to which its ends are connected, even when the coil passes the neutral plane of the dynamo, the electro-motive force of self-induction produces a local current through this coil; and when the one end of the coil slips past the brush and becomes a part of the other half of the divided circuit the current which should reverse through it meets the opposing current and breaks over the gap to the brush with a spark. Hence, the commutation must not take place at the neutral plane but in advance of it, and in a field where the induced electro-motive force in

the coil shall be just sufficient to offset the self-induction and in addition shall reverse the current in the coil while it is passing the brush or pair of brushes, and cause it to grow to the normal value at the instant when one end of it passes out from under the brush. The induction from the field must be sufficient to bring the one current to zero and to set an opposite one of equal value flowing in the coil, during the time it is under the brush. Then the commutation will be sparkless.

Now, if the current is kept constant in strength the field induction required to accomplish the results described is approximately the same whether the coil is short-circuited at one angle or another in advance of the neutral plane. It would appear at first thought that, unless the induction in every part of the field from the neutral plane to a point nearly 90° in advance of it is substantially uniform terrific sparking must result when the brushes are shifted far forward to vary the electric pressure to suit the requirements of the circuit; for if the induction is in excess of the requirements to accomplish the result described in the commuted coil then a current will circulate through it during the short-circuit, and the rupture of this on leaving the brush will cause sparking. I have illustrated this action in the following manner: Separately excite the field magnets of a machine, which can run on short-circuit even with a forward displacement of the brushes without sparking. Then leaving the armature on open circuit, rock the brushes forward; the sparking will increase with each advance till it becomes terrific and endangers the machine. The induction to which each coil is subjected in an excited field produces a large current in it while it is under the brush, since there is less self-induction in the coil to offset the induction from the field than there is when the machine is self-excited and working in the normal way. There is another reason to be described later.

Considerations of this kind have led some writers to say that sparkless commutation for any position of the brushes can be accomplished only when the induction in the field is made uniform. The Statter constant current machine in Eng-

land is made on this principle. Portions of the pole pieces are laboriously cut away at such points as to make the density of the lines of force entering the armature over a given angle equal. Of course, a machine built in this way will permit of shifting the brushes through a considerable angle in order to vary the potential difference without introducing sparking.

But while a uniform field accomplishes the result, no such uniformity is required; the same result may be secured in other ways. The first method already described weakens the field when the brushes move forward by cutting out ampère-turns in the field magnets. This reduces the induction to the proper amount at each point without changing the overlap of the brushes. It is made necessary by the very high saturation of the armature core in this machine. It has the advantage of greater economy with small loads because field resistance is cut out, but it requires a more complex arrangement of parts on the machine than suffices for the mere movement of the brushes.

[*To be concluded.*]

SUBDIVISION OF STEAMSHIPS AND SAFETY IN CASE OF INJURY.

By Andrew Ham.

[*Read at the meeting of the Section of Engineers and Naval Architects, November 23, 1893.*]

[*Concluded from p. 77.*]

The position *W L* (see *Fig. 3*) I suppose to be found in the usual way and start from this imaginary position.

Now, we may suppose the water contained in the ship up to *W L* to be solid, and to form part of the ship (say); it freezes without altering its density, provided that in the way of the compartments the sea has free access to the parts above *W L*—which we may express by saying that the part *n p q s t r u v n* of the load water plane is ineffective for giving stability.

This part we call the lost area of load water plane; that

part of the water plane which is left we call the effective water plane.

We readily see that:

(1) The ship begins to turn around an axis $A_1\ A\ A_2$.

(2) This axis passes through the centre of area A of the effective water plane and makes a small angle with the longitudinal axis of the ship. (See Appendix.)

For practical purposes this axis may be supposed to coincide with the fore and aft line through A.

(3) The ship will heel over till the centre of gravity, for

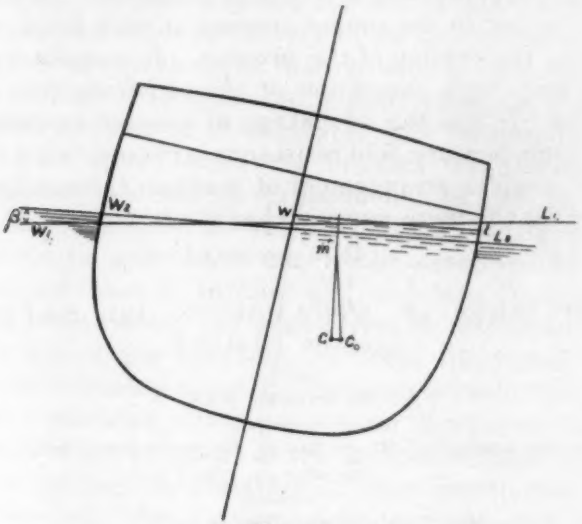


FIG. 2.

the imaginary case (*i. e.*, ship and frozen water in compartments combined) lies in the vertical line passing through the centre of buoyancy of the total displacement minus the wedges above the lost area of water plane.

(4) It follows that volume wedge $W\ A\ W_1$ = volume effective wedge $L\ A\ L_1$ and the couple which these wedges give:

$$M = J.\ \delta.\ \sin\theta, \text{ approximately.}$$

J being the moment of inertia of the effective water plane about $A_1\ A_2$.

δ the weight of a cubic unit (of length) of water.

θ the angle of heel.

(5) The ship will behave in exactly the same way as the uninjured ship would behave, only the metacentric height is

$$M C_0 = \frac{J}{V + \Delta V}$$

V being the volume of displacement of the uninjured ship.

ΔV being the volume of the water in the compartment up to $W L$, which we suppose to be solid.

If G_0 be the centre of gravity for the uninjured ship, g_0 the centre of gravity of the solid water, then we find the centre of gravity for the two combined in G.

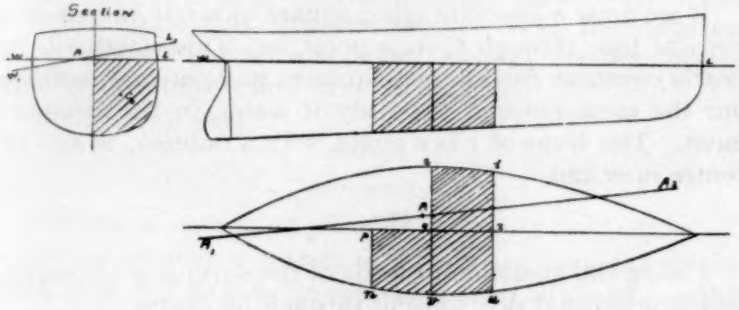


FIG. 3.

Let C_0 be the centre of buoyancy for the imaginary case, *i. e.*, the centre of volume of the hull below $W L$.

To find the position of equilibrium, set off

$$C_0 M = \frac{J}{V + \Delta V}$$

draw $M G$ and find θ by measuring.

[NOTE.—In general, the lost part of the water plane is not totally ineffective, and we have to deduct only a certain percentage of its area, moment and moment of inertia, percentage which is the same as that of the compartments below.]

We have found the position of statical equilibrium of the injured ship. This is the position around which the ship oscillates when rolling in still water or on the waves.

A problem, distinctly different from the one solved, is: What will be the stability of the ship now? and I will proceed to settle the remaining point.

I start with another supposition, viz: that the ship be flooded up to $W_1 L_1$ (*Fig. 1*), but uninjured, for instance, that we fill the compartment by pumping water in it up to $W_1 L_1$. Next, we incline the ship through a small angle β; then the section of the surface of the water in the compartment will be $w l$. In this inclined position the centre of volume of the flooding water will have moved from C_0, its position for the position of equilibrium, to c. Calling $\triangle D$ the weight of the water in the compartment, we might suppose $\triangle D$ concentrated in C.

But this centre moves away with every inclination the ship takes, and its position is a function of that inclination, and the form of the boundaries of the compartments.

If we draw a line through c_1 square to $w l$, it intersects a vertical line through C_0 in a point m. This point will be nearly constant for all inclinations; it is, in fact, nothing but the metacentre of the body of water in the compartment. The locus of c is a circle, with a radius $c_0 m$ and its centre in m and

$$m c_0 = \frac{i}{\triangle v}$$

i being the moment of inertia of the surface $w l$ in regard to a longitudinal axis passing through its centre.

$\triangle v$ being the volume, corresponding to $\triangle D$.

So that the water will act in the same manner as a weight $\triangle D$, fixed in m, would act.

Now, when the injured ship is rolling, there will be no time for the sea to fill the space between $W_2 L_2$ and $w l$; or, as in *Fig. 2*, for the water between these planes, to flow out. Consequently our supposition is practically realized.

To calculate the stability of the ship, therefore, we must suppose the water plane to be effective over its whole area, provided that we take the centre of gravity of the ship to be that of the uninjured ship and, $\triangle D$ supposed fixed in m, combined.

This calculation, however, would be of little use. For nobody knows what the water will do. It may have a natural period of oscillation, non-isochronous with the period of rolling of the ship and then its effect may be most dangerous.

And again, its period may be such as to counteract the rolling of the ship, in which case it will act as a water chamber.

This natural period of oscillation cannot be calculated, but might be found by tank experiments in a way similar to Froude's experiments, and based on the universal law of mechanical similarity. It will mostly depend on the height of water above the upmost immersed deck or flat. For the water below such a deck takes no part in the oscillating motion; it is bodily elevated or lowered.

That the effect of free water inside a ship is tremendous is proved by experience with water chambers. To reduce the rolling by fifty per cent., a properly constructed water chamber, containing one-two-hundredths of the displacement, was found sufficient; that is to say, for the *Lucania* about eighty tons would have this effect.

November 13, 1893.

APPENDIX.

Position of axis $A\ A'$.

Let us assume a system of coördinate axes, the origin being in A, $A\ Y$ situated in the water plane $W\ L$ and parallel to the plane of symmetry of the ship, $A\ X$ being perpendicular to that plane. The boundary of the water plane is the water line; its equation be

$$x_0 = f(y) \qquad (1)$$

Let α be the angle which $A_1\ A_2$ makes with $A\ Y$ (*Fig. 4.*)

M the magnitude of that couple.

$dF = dx\ dy$ an element of the water plane.

μ its percentage, $\mu = 1$ for effective area.

δ the weight of a cubic unit of water.

p the distance of dF from $A_1\ A_2$.

θ the angle of inclination.

β the angle which the axis of the couple, tending to heel the ship, makes with $A\ Y$.

Then M may be resolved in

$$M_x = M \sin \beta$$

$$M_y = M \cos \beta$$

The weight of an elementary perpendicular cylinder of the wedge, the base of which is $d\,F$ is

$$\mu \,.\, \delta \,.\, p \tan \theta \, d\,F = d\,P$$

giving p its proper sign.

The conditions of equilibrium are expressed by the following equations:

$$-M \sin \beta = \int y \, d\,P = \delta \,.\, \tan \theta \,.\, \int y \,.\, p \,.\, \mu \,.\, d\,F \qquad (2)$$

$$-M \cos \beta = \int x \, d\,P = \delta \,.\, \tan \theta \,.\, \int x \,.\, p \,.\, \mu \,.\, d\,F \qquad (3)$$

$$o = \int d\,P = \delta \,.\, \tan \theta \int \mu \, p \, d\,F \qquad (4)$$

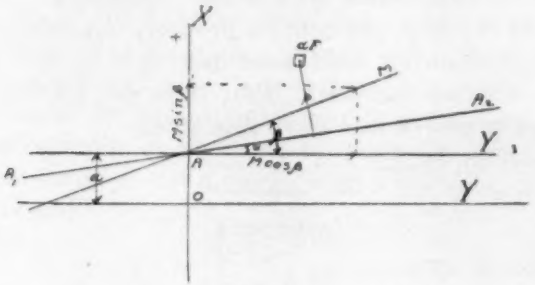


FIG. 4.

The limits of these integrals being determined by (1)

$$x_o = f(y)$$

(4) shows that $A_1\, A_2'$ must pass through the centre of the water plane.

(2) and (3) give M in function of β, x_o, y and p.

But

$$p = x \cos \alpha - y \sin \alpha \qquad (5)$$

consequently

$$-M \sin \beta = \delta \,.\, t\,g\,\theta \int (x\,y \cos \alpha - y^2 \sin \alpha)\, \mu \, d\,F \qquad (6)$$

$$-M \cos \beta = \delta \, t\,g\,\theta \int (x^2 \cos \alpha - x\,y \sin \alpha)\, \mu \, d\,F \qquad (7)$$

or

$$-\frac{M}{\delta \, t\,g\,\theta} \sin \beta = \cos \alpha \int x\,y\,\mu \, d\,F - \sin \alpha \int y^2\, \mu \, d\,F \qquad (8)$$

$$-\frac{M}{\delta \, t\,g\,\theta} \cos \beta = \cos \alpha \int x^2\, \mu \, d\,F - \sin \alpha \int x\,y\,\mu \, d\,F \qquad (9)$$

$\int x\,y\,\mu \, d\,F$ is called the product of inertia.

$\int y^2\, \mu \, d\,F$ is the longitudinal moment of inertia of the water plane.

$\int x^2 \mu \, dF$ is the transverse moment of inertia of the water plane.

$\int x y \mu \, dF$ is a quantity which becomes $= o$ when OX and OY are principal axes of inertia of the injured water plane.

In the case which we consider

$$\beta = o \therefore \sin \beta = o$$

consequently, from (8)

$$\tan a = \frac{\int x y \mu \, dF}{\int y^2 \mu \, dF} \tag{10}$$

which shows that a is the quotient of the product of inertia by the longitudinal moment of inertia.

Let F_0 be the total intact water plane, F_1, F_2, F_3, etc., the parts of the lost area, covering the respective compartments, ΔV_1, ΔV_2, ΔV_3, etc., μ_1, μ_2, μ_3, the corresponding percentages.

As μ_1, μ_2, μ_3, etc., are uniform over the respective areas, F_1, F_2, F_3, we may write:

$$\int_o^F \mu x^2 \, dF = \int_o^{F_0} x^2 \, dF_0 - (1 - \mu_1) \int_o^{F_1} x^2 \, dF_1 -$$

$$- (1 - \mu_2) \int_o^{F_2} x^2 \, dF_2 \tag{11}$$

$$\int_o^T \mu y^2 \, dF = \int_o^{T_1} y^2 \, dF_0 - (1 - \mu_1) \int_o^{F_1} y^2 \, dF_1 -$$

$$- (1 - \mu_2) \int_o^{F_2} x^2 \, dF_2 \tag{12}$$

$$\int_o^F \mu x y \, dF = \int_o^{F_0} x y \, dF_0 - (1 - \mu_1) \int_o^{F_1} x y \, dF_1 -$$

$$- (1 - \mu_2) \int_o^{F_2} x y \, dF_2 \tag{13}$$

where the limits of the integrals are determined by the boundaries of the respective areas.

To determine the value of the product of inertia of an area, we write:

$$\int x\, y\, d\, F = \int \int x\, y\, dy\, dx \tag{14}$$

As to the limits of the double integral, I remark that eq. (1)

$$x_0 = f\,(y)$$

admits two values of x for every value of y. One of these, x_0' is negative, the other: x_0'' may be positive or negative, but always $x_0' < x_0''$, except at the ends: ($y = -l_1$ and $y = +l_2$) where $x_0' = x_0 = -a$ when a is the distance of A from $O\ Y$, the centre line of the intact water plane.

Consequently,

$$\int_0^F x_0\, y\, d\, F = \int_{-y_0}^{+y_1} \int_{x_0'}^{x_0''} x_0 y\, dy\, dx_0 \tag{15}$$

Now we have, for both positive and negative values of x'',

$$\int_{x_0'}^{x_0''} x\, y\, dx = \int_{x_0'}^{0} x\, y\, dx + \int_0^{x_0''} x\, y\, d\, x = -\frac{x_0'^2}{2} y + \frac{x_0''^2}{2} y \tag{16}$$

Consequently (15) becomes

$$\int_0^F x_0\, y\, d\, F = \tfrac{1}{2} \int_{-y_0}^{+y_1} (x_0''^2 - x_0'^2)\, y\, dy \tag{17}$$

which permits us to find the value of the product of inertia of any figure by Simpson's or any other approximating rule.

We will, however, try to simplify (13).

Let us write the equation of the water-line, taking $O\ Y$ and $O\ X$ as axes

$$x = \varphi\,(y) \tag{18}$$

then, this equation admits two values, x' and x'', the latter being positive, while

$$-x' = +x'' = x$$

(18) is obtained by changing x_0 in (1) in $x - a$, and

$$\left.\begin{aligned} x_0' &= x' - a = -x - a \\ x_0'' &= x'' - a = x - a \end{aligned}\right\} \tag{19}$$

consequently, by (17) and (19)

$$\int_{o}^{F_o} x_o \, y \, d \, F_o = - \, 2 \, a \int_{y_o}^{y_1} x \, y \, dy \qquad (20)$$

but in (20)

$$\int_{y_o}^{y_1} x \, y \, dy$$

is the moment of the figure about $o \, x$, so that (20), translated, says:

The product of inertia of a symmetrical figure about axes Ax, $A \, Y$, $A \, Y$ being parallel to the axis of symmetry of the figure at a distance a from that axis, $A \, X$ being square to $A \, Y$, equals the product obtained by multiplying the moment of the figure about Ax by $- \, 2 \, a$.

This, consequently, is not only true for F_o, but also holds good for those areas F_n which are situated in compartments without a longitudinal bulkhead.

For compartments with a longitudinal bulkhead $b \, b$, we have

$$\left.\begin{aligned} x_o' &= - \, x - a \\ x_o'' &= c - a \end{aligned}\right\} \qquad (21)$$

c being the distance of the bulkhead from the centre line $O \, Y$, positive or negative.

Consequently, by (17) and (21)

$$\int_{o}^{F_n} x_o \, y \, d \, F_n = \tfrac{1}{2} \int_{l_n - 1}^{l_n} \left\{ c \, (c - 2 \, a) - x \, (x + 2 \, a) \right\} \, y \, dy \qquad (22)$$

l_{n-1} and l_n being the values of y for the bounding transverse bulkheads b_{n-1} and b_n.

To simplify, we suppose $c = o$ as is generally the case in practice, making

$$\int_{o}^{F_n} x_o \, y \, d \, F_n = - \, \tfrac{1}{2} \int_{l_n - 1}^{l_n} x^2 \, y \, dy - a \int_{l_n - 1}^{l_n} x \, y \, dy \qquad (23)$$

Now, according to (17)

$$-\tfrac{1}{2}\int_{l_n-1}^{l_n} x^2\, y\, dy$$

is the product of inertia of F_n about $O\ Y$, $O\ X$.

And

$$\int_{l_n-1}^{l_n} x\, y\, dy$$

is the moment of F_n about $O\ X$.

Let us denote by F_n in general those areas which are symmetrical about $O\ Y$, M_n their moments about $O\ X$.

F_m those areas which are on one side of $O\ Y$, M_m their moments about $O\ X$, L_m their products of inertia about $O\ X$, $O\ Y$.

Then, by virtue of eq. (20) and (23), eq. (13) becomes

$$\int_o^F x\, y\, \mu\, d\, F = -\,2\, a\, M_o + 2\, a\, \Sigma\,(1-\mu_n)\, M_n + \\ + a\, \Sigma\,(1-\mu_m)\, M_m - \Sigma\,(1-\mu_m)\, L_m \qquad (24)$$

But, as A is the centre of area of F

$$o = M_o - \Sigma\,(1-\mu_n)\, M_n - \Sigma\,(1-\mu_m)\, M_m \qquad (25)$$

eq. (24) becomes

$$\int_o^F x_o\, y\, d\, F = -\,a\, \Sigma\,(1-\mu_m)\, M_m - \Sigma\,(1-\mu_m)\, L_m \qquad (26)$$

where

$$L_m = -\tfrac{1}{2}\int_{l_m-1}^{l_m} n^2\, y\, dy$$

Or:

The product of inertia of the effective water plane is equal to the sum of certain functions of the lost areas F_n on one side.

This function for such an area F_n is the sum of two quantities. The first is its moment about $O\ X$, multiplied by $-\,a\,(1-\mu_n)$. The second is the product of inertia of that area about $O\ X$, $O\ Y$, multiplied by $-\,(1-\mu_n)$.

Franklin Institute.

[*Proceedings of the annual meeting, held Wednesday, January 17, 1894.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, January 17, 1894.

Mr. SAMUEL SARTAIN in the chair.

Present, 228 members and thirty-six visitors.

The annual election resulted in the choice of the following candidates, viz:

For *President*	(to serve one year), . . .	JOSEPH M. WILSON.
" *Vice-President*	(" three years), . . .	W. P. TATHAM.
" *Secretary*	(" one year), . . .	WM. H. WAHL.
" *Treasurer*	(" " "), . . .	SAMUEL SARTAIN.
" *Auditor*	(" three years), . . .	W. O. GRIGGS.

For the *Board of Managers* (to serve three years).

ARTHUR BEARDSLEY,	CHAS. G. DARRACH,	M. R. MUCKLE, JR.,
HENRY BOWER,	HENRY R. HEYL,	HENRY PEMBERTON, JR.,
CHAS. A. BRINLEY,	H. W. JAYNE,	HORACE PETIT,

For the *Committee on Science and the Arts* (to serve three years).

H. BRINTON,	SPENCER FULLERTON,	S. P. SADTLER,
JOHN E. CODMAN,	W. C. HEAD,	CLARENCE B. SCHULTZ,
H. F. COLVIN,	HENRY R. HEYL,	THOS. SHAW,
THOS. P. CONARD,	FRED. E. IVES,	E. G. WILLYOUNG,
CHAS. B. DUDLEY,	C. L. PRINCE,	PAUL A. WINAND.

The annual reports of the Board of Managers, of the several Standing Committees and Sections of the Institute, and of the Trustees of the Elliott Cresson Fund, were presented and accepted.

Mr. George D. Burton, of Boston, who was present by special invitation, read a paper descriptive of his method of heating metals by the employment of a saline electrolytic bath as a resistance. He proceeded to give an extremely interesting practical demonstration of the method, with an apparatus consisting of an ordinary wooden bucket containing a saturated aqueous solution of a mixture of sal soda and borax, a lead plate connecting with the positive terminal of a direct current serving as the positive electrode (or anode), and the metallic object to be treated connected with the negative terminal of the circuit serving as the negative electrode (or cathode), the circuit being completed through the salt solution, where the metallic article forming the cathode is brought in contact with, or immersed beneath the sur-

face of the bath. This disposition of apparatus is the invention of Mr. Burton, and has been appropriately named the "water-pail forge." The circuit employed by Mr. Burton in his experiments was the 220-volt Edison incandescent service. With the apparatus installed in the manner described above, Mr. Burton successfully exhibited the efficiency by heating to bright incandescence, and even to fusion, in from ten to thirty seconds, rods and bars of iron, steel, copper and carbon. The metal objects were then forged, welded, etc., in the anvil.

The demonstration excited fresh interest and considerable discussion followed, at the close of which the thanks of the meeting were voted to Mr. Burton for his extremely interesting demonstration, and the subject was directed to be referred to the Committee on Science and the Arts for investigation and report.

Prof. Joseph W. Richards gave some account of the methods that had heretofore been described and used for soldering aluminum, and referred to the very serious difficulties which inventors had met in their efforts to find a practical method. He then proceeded to describe the plan devised by his father, Mr. Joseph Richards, which involves the use of phosphorized alloys for the purpose, the function of the phosphorus being to remove the thin film of oxide always present on the surface of aluminum, and which renders soldering so very difficult. At the close of the remarks the application of the method was shown practically, in a very satisfactory way.

The meeting passed a vote of thanks to Mr. Richards for his interesting demonstration and the subject of the invention was referred to the Committee on Science and the Arts.

The Secretary read a brief description of an improved system of electric railway conduit, devised by Mr. Wm. R. DeVoe, of Shreveport, La., and illustrated the subject by the exhibition of a model. The Secretary also referred to a method of depositing metallic chromium electrolytically, devised by M. Placet, a French electrician, and exhibited specimens of the metal and of a number of articles of copper that were electroplated with chromium. These specimens were sent for exhibition by Mr. Anthony Pollok, of Washington, D. C.

A letter was read from Mr. Wm. Sellers declining a renomination to membership on the Board of Managers. Whereupon, on motion of Mr. John H. Cooper, duly seconded, the following resolution was unanimously adopted, viz:

Resolved, That the Institute accepts the resignation of Mr. Wm. Sellers with regret, and directs that record be made in its proceedings of its high appreciation of his long and useful services as a member of its Board of Managers and its President.

Adjourned.

WM. H. WAHL, *Secretary*.

PENNSYLVANIA STATE WEATHER SERVICE,

UNDER THE DIRECTION OF THE FRANKLIN INSTITUTE,

CO-OPERATING WITH THE

UNITED STATES DEPARTMENT OF AGRICULTURE, WEATHER BUREAU

T. F. TOWNSEND, WEATHER BUREAU, L. F. O. IN CHARGE.

MONTHLY WEATHER REVIEW.

FOR DECEMBER, 1893.

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 31, 1893.

GENERAL REVIEW.

December's normal temperature and rainfall is about 32°·8 and 3·18 inches. The present month has been 0°·7 colder than the average, and the rainfall 0·12 of an inch less.

The warmest day was the 25th, and the coldest were the 5th and 14th.

With the exception of the 8th, precipitation was reported on every day of the month from some portion of the State. General rains were numerous.

March, 1894, will complete the series of charts (twelve months) showing by isothermal lines the normal temperature of each month. Their publication will be discontinued after that date. The series should be preserved for future reference.

From January 1, 1893, to December 31, 1893, the deficiency in temperature at Philadelphia was 303°; Pittsburgh, 491°; York, 457°, and Erie, 469°.

For the same period the deficiency in precipitation at Philadelphia was 2·91; York, 8·00; Erie, 2·72, and excess at Pittsburgh, 0·36 inch.

	Mean Temperature.	*Mean Precipitation. Inches.*
December, 1887, ...	31°·5	3·53
1888, ...	32°·6	3·14
1889, ...	39°·3	2·77
1890, ...	27°·5	3·97
1891, ...	38°·6	4·09
1892, ...	27°·9	1·69
1893, ...	32°·1	3·06

TEMPERATURE.

The mean temperature for December, 1893, was 32°·1, which is 0°·7 below the normal, and 4°·2 above the corresponding month of 1892.

The means of the daily maximum and minimum temperatures, 40°·4 and 24°·1, gives a monthly mean of 32°·2, with an average daily range of 16°·3.

Highest monthly mean, 37°·2 at Uniontown.

Lowest monthly mean, 27°·1 at Le Roy and Smethport.

Highest temperature recorded during the month, 70° on the 24th at Easton.

Lowest temperature, minus 7° on the 14th at Dyberry.

Greatest local monthly range, 65° at Drifton.

Least local monthly range, 41° at Chambersburg.

Greatest daily range, 58° at Drifton on the 29th.

Least daily range, 1° at Hamburg, 26th; Chambersburg, 11th.

BAROMETER.

The mean pressure for the month, 30·14, is about ·08 above the normal. At the United States Weather Bureau Stations, the highest observed was 30·88 at Philadelphia, on the 14th, and the lowest 29·47 at Erie on the 16th.

PRECIPITATION.

The average rainfall, 3·06 inches for the month, is a deficiency of 0·12 inch.

The largest monthly totals in inches were Smethport, 6·07; Salem Corners, 4·25; Wellsboro, 4·21; Shingle House, 4·13.

The least were Bloomsburg 1·41; Carlisle, 1·60, and Somerset, 1·75.

WIND AND WEATHER.

The prevailing wind was from the West.

Average number: rainy days, 12; clear days, 6; fair days, 11; cloudy days, 14.

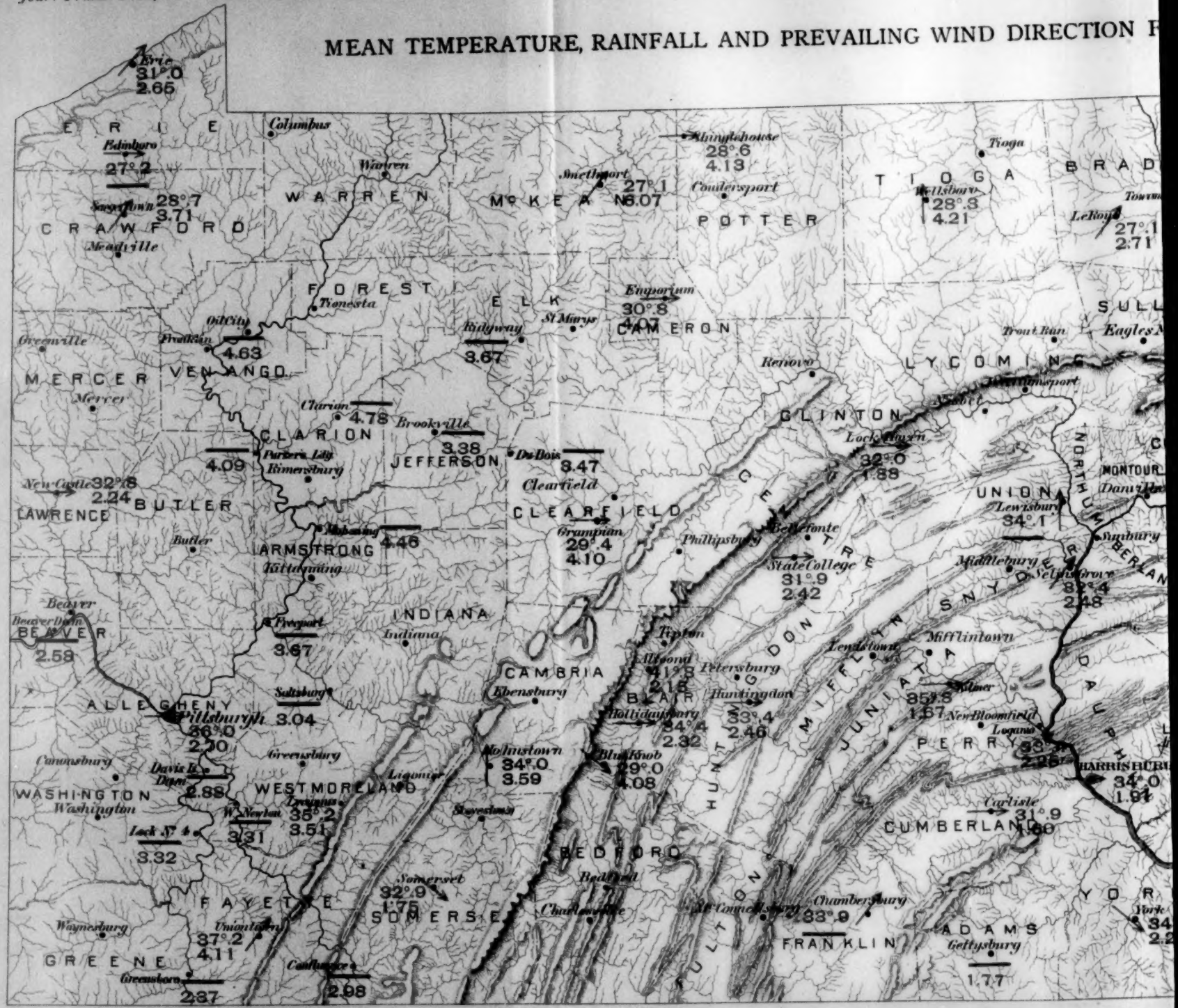
MISCELLANEOUS PHENOMENA.

Thunder.—Hollidaysburg, 25th, 26th; Saegerstown, 25th; Smethport, 25th; Aqueduct, 25th; Selins Grove, 25th; Wellsboro, 25th; Dyberry, 25th; South Eaton, 25th.

Hail.—Blue Knob, 26th; Westtown, 30th, 31st; Dyberry, 3d, 15th; York, 15th, 28th.

Snow.—Hamburg, 3d, 5th, 15th; Altoona, 3d, 10th, 15th, 28th, 31st; Blue Knob, 1st, 2d, 3d, 4th, 7th, 11th, 13th, 14th, 16th, 17th, 18th, 19th, 26th, 27th, 28th, 30th, 31st; Hollidaysburg, 1st, 3d, 8th, 14th, 16th, 17th, 19th, 30th, 31st; Le Roy, 1st, 3d, 4th, 12th, 13th, 14th, 17th, 18th, 19th, 27th, 28th, 30th, 31st; Quakertown, 5th, 9th, 14th, 30th, 31st; Johnstown, 7th, 10th, 13th, 16th, 17th, 18th, 19th, 20th, 31st; Emporium, 1st, 2d, 3d, 4th, 7th, 9th, 10th, 11th, 12th, 13th, 14th, 16th, 17th, 18th, 19th, 20th, 26th, 27th, 28th, 31st; State College, 3d, 18th, 19th, 28th, 30th, 31st; Coatesville, 3d, 5th, 31st; Kennett

MEAN TEMPERATURE, RAINFALL AND PREVAILING WIND DIRECTION F


Erie 31°.0 2.65
Columbus
Edinboro 27°.2
Warren
Rhinelhouse 28°.6 4.13
Smethport 27°.1 4.07
Coudersport
Tioga
Wellsboro 28°.3 4.21
Sagertown 28°.7 3.71
Meadville
Tionesta
Emporium 30°.8 4.07
Oil City
Franklin 4.63
Ridgway 3.67
St Marys
Greenville
Mercer
Clarion 4.78
Brookville 3.38
Renovo
Trout Run
Eagles M
Lock Haven 32°.0 1.88
Clinton
Lewisburg 34°.1
Montour
Dan
Sunbury
Middleburg
Selinsgrove 32°.4 2.48
Mifflintown
Lewistown
Juniata
Snyder
Perry
Harrisburg 34°.0 1.91
Carlisle 31°.9 1.80
Cumberland
Adams
Gettysburg 1.77
Franklin
Chambersburg 33°.9
Fulton
Bedford
Somerset 32°.9 1.75
Somerset
Huntingdon
Huntingdon 33°.4 2.46
Blair
Hollidaysburg 34°.4 2.32
Altoona 41°.3 2.16
Tipton
Cambria
Ebensburg
Johnstown 34°.0 3.59
Blue Knob 29°.0 4.08
Allegheny
Pittsburgh 36°.0 2.20
Saltsburg 3.04
Indiana
Freeport 3.67
Armstrong
Kittanning
Mahoning 4.46
Butler
Beaver
Beaver Dam
Beaver 2.58
Lawrence
New Castle 32°.8 2.24
Rimersburg
Punxsy Lily
4.09
Jefferson
DuBois 3.47
Clearfield
Grampian 29°.4 4.10
Phillipsburg
Bellefonte
State College 31°.9 2.42
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Erie
Crawford
Meadville
Venango
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Greensburg 2.87
Uniontown 2.98
Somerset 1.75
Bedford
Chambersburg 33°.9
Gettysburg 1.77
Carlisle 31°.9 1.80
Harrisburg 34°.0 1.91
Lewisburg 34°.1
Selinsgrove 32°.4 2.48
Lock Haven 32°.0 1.88
State College 31°.9 2.42
Grampian 29°.4 4.10
DuBois 3.47
Brookville 3.38
Clarion 4.78
Oil City
Franklin 4.63
Ridgway 3.67
Emporium 30°.8 4.07
Smethport 27°.1 4.07
Rhinelhouse 28°.6 4.13
Coudersport
Wellsboro 28°.3 4.21
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LeRoy 27°.1 2.71
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Waynesburg 4.11
Washington
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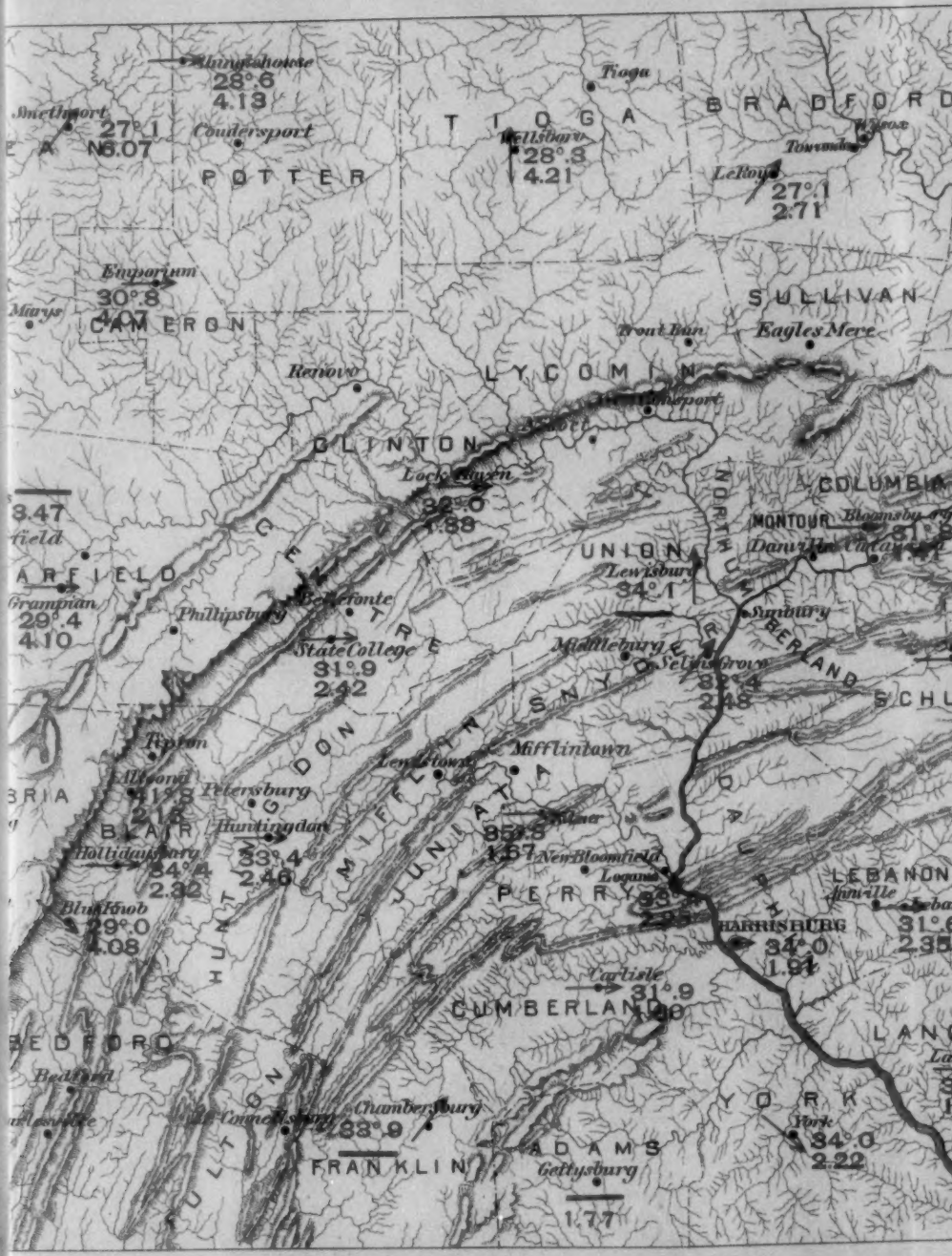
Davis Dam 2.88
Greensburg
Ligonier
Johnstown 34°.0 3.59
Blue Knob 29°.0 4.08
Stoystown
Somerset
Lock № 4 3.32
W Newton 3.31
Dravosburg 35°.2 3.51
Pittsburgh 36°.0 2.20
Saltsburg 3.04
Indiana
Freeport 3.67
Kittanning
Mahoning 4.46
Butler
Beaver
Beaver Dam
Beaver 2.58
New Castle 32°.8 2.24
Rimersburg
Punxsy Lily
4.09
Clarion 4.78
Brookville 3.38
DuBois 3.47
Clearfield
Grampian 29°.4 4.10
Phillipsburg
Bellefonte
State College 31°.9 2.42
Oil City
Franklin 4.63
Ridgway 3.67
Emporium 30°.8 4.07
St Marys
Tionesta
Meadville
Sagertown 28°.7 3.71
Edinboro 27°.2
Erie 31°.0 2.65
Columbus
Warren
Smethport 27°.1 4.07
Rhinelhouse 28°.6 4.13
Coudersport
Tioga
Wellsboro 28°.3 4.21
LeRoy 27°.1 2.71
Renovo
Trout Run
Eagles M
Lewisburg 34°.1
Selinsgrove 32°.4 2.48
Lock Haven 32°.0 1.88

RE, RAINFALL AND PREVAILING WIND DIRECTION FOR DE



FOR DECEMBER. 1893

PRECIPITATION DURING DECEMBER, 1893.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
Delaware Basin.																																
Blooming Grove,	..	..	.60	1.18	..	..	..	..	..	..	..	..	..	.70	.12	..	.66	..	..	..	.05	..	..	.45	..	..	..	..	..	.20	..	3.30
Browers Lock,	.05	..	.42	.55	.38	.04	..	..	.16	.04	..	..	..	..	.23	..	..	..	..	..	..	..	.08	..	..	..	..	..	.08	.42	.11	3.13
Coatesville,	.04	..	.77	.21	.55	..	..	..	.15	..	..	..	..	..	.29	.90	..	..	..	..	..	.12	.03	..	..	..	..	..	.05	..	.57	..	3.68
Coopersburg,	.03	..	.85	.18	.40	..	..	..	.03	.01	..	..	..	.03	.18	.50	..	..	..	..	..	.02	.04	.03	..	..	..	..	..	.11	.10	.07	2.64
Doylestown,	.11	..	.76	.25	.34	..	..	..	.16	.04	..	..	..	..	.09	.21	..	..	..	..	..	.04	..	..	..	..	..	..	.13	.15	.05	2.33
Dyberry,	..	..	.96	.30	.17	..	..	..	..	..	..	..	..	.45	.38	.10	..	..	..	..	..	..	.15	..	..	.40	..	.02	.16	.10	.13	3.32
Easton,	.04	..	.25	1.12	.40	.14	..	..	..	.08	..	..	..	..	.07	..	..	..	..	..	..	..	..	..	..	.37	.01	..	.06	..	.10	3.24
Forks of Neshaminy,	.10	..	1.08	..	.16	..	..	..	.16	.02	..	..	..	..	.27	.78	..	..	..	..	..	.04	.02	..	.02	..	..	.02	.08	.18	.04	2.97
Frederick,	.04	..	.88	.23	.34	..	..	..	.14	.04	..	..	..	..	.25	.68	..	..	..	..	..	..	.06	..	..	..	..	..	.13	.17	.03	2.99
Hamburg,	..	..	1.40	..	.42	..	..	..	..	..	..	..	..	..	.33	.58	..	..	..	..	..	.02	..	..	..	..	..	..	..	..	.32	3.07
Honesdale,	..	..	1.53	..	.23	..	..	..	..	..	..	..	..	.60	.56	.10	..	..	.06	..	..	..	.12	..	.02	..	..	.03	.60	.08	.15	4.08
Kennett Square,	.03	..	.55	.25	.45	..	..	..	.13	.03	..	..	..	..	.30	.80	..	..	..	..	..	.10	.01	..	..	..	..	.04	.04	.52	.04	3.29
Lansdale,	..	.10	.83	.15	.40	..	..	..	.16	.03	..	..	..	..	.23	.80	..	..	..	..	..	.04	..	..	..	..	..	..	.12	.14	.05	3.05
Mauch Chunk,	.02	..	.94	.32	.38	..	..	..	.01	.02	..	..	..	..	.36	.42	..	..	..	..	..	.03	.07	..	..	.14	..	.05	.07	..	.11	2.84
Ottsville,	..	.10	.61	..	.80	.15	..	..	.11	..	..	..	..	..	.14	.78	.02	..	..	..	..	.05	.07	.04	..	..	..	..	.20	..	..	3.07
Philadelphia, a†	.05	..	.35	.52	.24	..	..	..	.15	.01	..	..	..	..	.25	1.03	..	..	..	..	..	.01	.01	..	..	..	..	.03	..	.44	.04	3.13
Philadelphia, b,	.05	..	.45	.52	.23	..	..	..	.15	.01	..	..	..	..	.24	1.09	..	..	..	..	..	.02	.02	..	..	..	..	.04	..	.51	.03	3.36
Phœnixville,	.06	..	.68	.21	.22	.06	..	..	.15	.04	..	..	..	..	.28	.83	..	..	..	..	..	.09	.06	.03	..	..	..	.03	.05	.10	.16	3.05
Point Pleasant,	.07	..	1.12	.08	.41	..	..	..	.18	..	..	..	..	.02	.25	.72	..	..	..	..	.03	.04	.02	..	..	..	..	.03	.17	.14	.03	3.30
Pottstown,	..	..	.95	..	.80	..	..	..	..	.16	..	..	..	..	.23	.55	..	..	..	..	..	.06	..	..	..	..	..	..	..	.06	..	2.81
Quakertown,	.06	..	.95	.20	.50	..	..	..	.14	.07	..	..	..	..	.30	.67	..	..	..	..	..	.09	..	.04	..	..	..	..	.16	.26	.05	3.49
Reading,	.01	..	.57	.25	.20	..	..	..	.02	..	..	..	..	.01	.08	.45	..	..	..	..	..	.04	.02	.01	..	.01	..	.01	.11	.14	.06	1.99
Salem Corners,	..	..	.94	.33	..	.35	..	..	..	..	..	..	..	..	.98	.08	.27	..	.02	.05	..	..	.16	..	.09	.50	..	.01	.15	.02	.30	4.25
Seisholtzville,	..	..	.92	..	.36	..	..	..	..	..	..	..	..	..	.34	.45	..	..	..	..	..	..	..	..	..	..	..	..	.21	..	.23	2.51
Skippack,	..	..	.41	.10	.21	..	..	..	.09	..	..	..	..	..	..	.50	..	..	..	..	..	..	.03	..	..	..	..	*	*	*	*	1.34
Smith's Corner,	.08	..	.92	.25	.31	..	..	..	.17	.04	..	..	..	.03	.29	.77	..	..	..	..	..	.03	.04	.05	..	..	..	..	.22	.10	.07	3.39
Swarthmore,	.10	..	.50	..	.40	..	..	..	..	.27	..	..	..	..	.15	.85	..	..	..	..	..	.03	.07	..	..	..	..	.02	..	.38	..	3.17
West Chester,	.04	..	.69	.20	.29	..	..	..	.09	.01	..	..	..	..	.47	.75	..	..	..	..	..	.12	.06	..	..	..	..	.02	.04	.55	.03	3.16
Westtown,	..	..	.71	..	.25	..	..	..	.20	..	..	..	*	..	.25	.73	..	..	..	..	*	.17	..	..	..	*	..	.16	..	.60	..	3.07
Susquehanna Basin.																																
Altoona,	..	..	.78	..	..	..	..	..	..	.01	..	..	..	..	.94	..	..	..	.01	..	..	..	.02	.02	..	.10	..	.05	.18	..	.04	2.15
Aqueduct,	..	..	1.15	..	..	..	..	..	..	..	..	..	..	.19	.12	.13	..	..	..	..	..	..	..	..	..	.07	..	.17	.09	.13	..	2.25
Bloomsburg,	..	..	.92	.09	..	..	..	..	..	..	..	..	..	.07	.06	..	..	..	..	..	..	.04	.02	..	..	..	..	..	.12	.07	.02	1.41
Blue Knob,	.20	..	.67	..	..	..	.02	..	.02	..	..	..	..	.10	1.16	.13	.20	.10	.30	..	..	..	.04	..	.02	..	..	.31	.51	.05	.25	4.08
Carlisle,	..	..	.40	.33	..	..	..	..	..	..	..	..	..	..	.28	.08	..	..	..	..	..	..	..	..	..	..	..	.01	.14	.28	.06	1.60
Drifton,	..	..	*	.30	.40	..	..	..	*	..	..	..	..	..	..	..	*	..	..	..	..	..	..	*	*	..	..	.20	.83	.20	*	1.93
Emporium,	.12	..	1.01	..	..	..	.03	..	.02	.16	.02	.01	..	.21	.93	.18	.03	.15	.10	.07	..	..	.22	.01	..	.26	..	..	.46	..	.08	4.07
Gettysburg,	..	..	.39	.31	..	.13	..	..	..	..	..	..	..	..	.14	..	.17	..	..	..	..	..	.06	..	..	..	..	..	.13	..	.44	1.77
Girardville,	..	.27	.83	..	.81	*	..	..	..	..	..	..	..	.24	.17	.43	..	..	..	..	..	.06	..	..	..	..	..	.02	.07	.17	.16	3.23
Grampian,	.12	..	1.18	..	..	..	..	..	..	.10	..	..	.02	.24	1.04	.22	..	.14	..	..	..	..	.07	.16	.06	.14	..	.11	.50	..	..	4.10
Harrisburg,†	..	..	.76	.17	.02	..	..	..	..	.04	..	..	..	.02	.21	.29	..	..	..	..	..	.01	.02	..	..	..	..	..	.15	.15	.07	1.91
Hollidaysburg,	..	.11	.76	..	..	..	..	..	..	.04	..	..	..	..	.96	.03	..	..	.04	..	..	..	..	..	..	..	..	.09	..	.08	.12	.04	.05	2.32
Huntingdon,	..	..	.30	..	..	..	..	..	..	.02	..	..	..	.05	.95	.05	..	..	..	..	..	..	.05	..	..	..	..	..	.18	.16	.05	.05	2.46
Kilmer,	..	.30	.03	..	..	..	..	..	..	..	..	..	..	.10	.32	.08	..	..	..	..	..	..	..	..	..	..	..	..	.19	.02	.03	..	1.67
Lancaster,	..	..	.63	.05	.35	..	..	..	..	..	..	..	..	..	.23	.43	..	..	..	..	..	..	.01	..	..	*	*	*	*	*	*	*	1.70
Lebanon,	..	..	.95	..	.28	..	..	..	..	..	..	..	..	.03	.21	.45	..	..	..	.01	..	..	.03	.04	..	..	..	..	.12	.16	.07	2.35
Le Roy,	.03	..	1.31	.01	..	..	..	..	.04	..	.02	..	..	.20	.24	.05	.03	.02	.03	..	..	..	.05	.02	.02	.30	..	.04	.22	.03	.03	2.71
Lewisburg,	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
Lock Haven,	..	..	1.04	..	..	..	..	..	..	..	..	..	..	.30	..	.02	..	.05	..	..	..	..	..	..	..	..	..	..	.38	.09	..	1.88
Selins Grove,	..	..	.36	..	..	..	..	..	..	..	..	..	..	.20	.06	1.34	..	..	..	..	..	..	..	..	..	.25	..	.05	.10	.10	.02	2.48
South Eaton,	..	..	.89	.11	.14	..	..	..	..	..	..	..	..	..	.32	.19	..	..	..	..	..	..	.06	.02	..	.42	..	..	.12	..	.19	2.46
State College,	..	..	1.09	..	..	..	..	..	..	.02	..	..	..	.03	.76	.10	..	..	..	..	..	.01	.03	..	..	.04	..	.05	.16	.05	.08	2.42
Wellsboro,	.03	..	1.20	..	..	..	..	..	.02	..	.05	..	..	.55	1.50	.24	..	.15	.10	..	..	..	..	..	.10	..	..	..	.20	..	.05	4.21
Wilkes-Barre,	..	..	1.98	..	.22	..	..	..	..	.10	..	..	..	.42	.26	.33	..	..	.04	..	..	..	.06	..	.18	..	..	.05	.05	..	.25	3.94
Wysox,	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..	..
York,	..	..	.67	.13	.30	..	..	..	.05	..	..	..	..	..	.14	.40	..	..	..	..	..	.03	.01	..	..	..	..	..	.07	.42	..	2.22

	1	2	3	4
Ohio Basin.				
Beaver Dam,	..	..	.86	.20
Brookville,	..	..	.34	.18
Clarion,	.25	.03	1.20	.20
Columbus,	..	..	..	..
Confluence,	.01	.02	.30	.35
Davis Island Dam,	..	.08	.93	.12
DuBois,	.03	.02	.10	..
Freeport,	.05	..	1.06	.05
Greensboro,	..	.03	.10	.15
Immel Reservoir,	.15	..	.89	..
Indiana,	..	..	..	..
Johnstown,	.07	.08	1.09	..
Ligonier,	..	..	..	..
Lock No. 4,	.02	..	.65	.23
Mahoning,	.03	.02	1.29	.14
Meadville,	..	..	..	..
New Castle,	.04	.06	.20	.13
Oil City,	.22	.05	.89	.20
Parker's Landing,	.08	.02	1.16	.16
Pittsburg,†	.04	.05	.74	.01
Ridgway,	..	.80	.15	..
Saegerstown,	..	..	..	.25
Saltsburg,	.04	.05	.85	.22
Shingle House,	.31	..	.61	.07
Smethport,	.45	..	1.10	.10
Somerset,	.04	..	.25	..
Stoyestown,	..	.44	.37	.89
Uniontown,	.02	..	.09	..
Warren,	.41	.19	1.24	.15
West Newton,	.03	..	.60	.34
Potomac Basin.				
Chambersburg,	..	..	..	..
McConnellsburg,	..	..	..	..
Lake Basin.				
Erie,†	.12	.06	.54	.01

†U. S. Weather Bureau Stations. * Missing.

PRECIPITATION DURING DECEMBER, 1893.

	1	2	3	4	5	6	7	8	9	10	11	22	23	24	25	26	27	28	29	30	31	Total.
Ohio Basin.																						
Beaver Dam,	.	.	.86	.20	.	.	.	.	.	.07	.	.	.	.45	.	.	.	.	.	.	.20	3.30
Brookville,	.	.	.34	.18	.	.	.	.	.	.11	.	.	.08	.	.	.	.	.	.08	.42	.11	3.13
Clarion,	.25	.03	1.20	.20	.02	.	.	.	.	.20	.	.12	.03	.	.	.	.	.	.	.57	.	3.68
Columbus,	.	.	.	.	.	.	.	.	.	.	.	.02	.04	.03	.	.	.	.	.11	.10	.07	2.64
Confluence,	.01	.02	.30	.35	.	.	.	.	.	.09	.	.04	.	.	.	.	.	.	.13	.15	.05	2.33
Davis Island Dam,	.	.08	.93	.12	.	.	.	.	.	.	.08	.	.15	.	.40	.	.02	.16	.10	.13	3.32
DuBois,	.03	.02	.20	.	.	.	.03	.	.	.	.	.	.	.37	.01	.	.06	.	.	.10	3.24
Freeport,	.05	.	1.06	.05	.	.	.	.	.	.06	.	.04	.	.02	.	.02	.	.02	.08	.18	.04	2.97
Greensboro,	.	.03	.50	.15	.	.	.	.	.	.10	.	.	.	.	.	.	.	.	.13	.17	.03	2.99
Immel Reservoir,	.15	.	.89	.	.	.	.	.	.	.09	.	.	.	.	.	.	.	.	.	.	.32	3.07
Indiana,	.	.	.	.	.	.	.	.	.	.	.	.12	.	.	.02	.	.	.	.03	.60	.08	4.08
Johnstown,	.07	.06	1.09	.	.	.	.	.	.02	.04	.	.10	.01	.	.	.	.	.	.04	.32	.04	3.29
Ligonier,	.	.	.	.	.	.	.	.	.	.	.	.04	.	.	.	.	.	.	.12	.14	.05	3.05
Lock No. 4,	.02	.	.65	.23	.	.	.	.	.	.08	.	.03	.07	.	.	.	.	.	.14	.07	.11	2.84
Mahoning,	.03	.02	1.29	.14	.	.	.	.	.	.10	.	.05	.07	.04	.	.	.	.	.	.20	.	3.07
Meadville,	.	.	.	.	.	.	.	.	.	.	.	.01	.02	.	.	.	.	.	.03	.	.44	3.13
New Castle,	.04	.06	.20	.13	.	.	.	.	.04	.	.02	.02	.02	.	.	.	.	.	.04	.51	.03	3.36
Oil City,	.22	.05	.89	.20	.	.	.	.	.	.14	.	.09	.06	.03	.	.	.	.	.03	.10	.16	3.05
Parker's Landing,	.08	.02	1.16	.16	.	.	.	.	.	.16	.	.04	.02	.	.	.	.	.	.03	.13	.03	3.30
Pittsburg,†	.04	.05	.74	.01	.	.	.	.	.03	.	.	.06	.	.	.	.	.	.	.	.	.	2.81
Ridgway,	.	.80	.15	.	.	.	.	.	.17	.	.	.09	.	.04	.	.	.	.	.16	.26	.05	3.49
Saegerstown,	.	.	.	.25	.31	.	.	.	.10	.	.	.04	.02	.	.	.	.	.	.01	.14	.06	1.99
Saltsburg,	.04	.05	.85	.22	.	.	.	.	.	.03	.	.03	.	.	.	.	.	.	.01	.15	.02	4.25
Shingle House,	.31	.	.61	.07	.	.	.	.	.	.08	.17	.16	.09	.	.	.	.	.	.	.21	.	2.51
Smethport,	.45	.	1.10	.10	.	.	.	.	.	.25	.10	*	*	*	*	*	*	*	*	*	*	1.34
Somerset,	.04	.	.25	.	.	.	.	.	.	.16	.	.03	.04	.05	.	.	.	.	.	.22	.10	3.39
Stoyestown,	.	.44	.37	.89	.	.	.	.	.04	.16	.	.03	.07	.	.	.	.	.	.02	.38	.	3.17
Uniontown,	.02	.	.69	.	.	.	.	.	.31	.	.	.12	.06	.	.	.	.	.	.02	.	.03	3.16
Warren,	.41	.19	1.24	.15	.	.	.	.	.	.39	.02	.17	.	.	.	.	.	.	.16	.60	.	3.07
West Newton,	.03	.	.60	.34	.	.	.	.	.	.05	.	.	.	.	.	.	.	.	.	.	.	
Potomac Basin.																						
Chambersburg,	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	.	2.15
McConnellsburg,	.	.	.	.	.	.	.	.	.	.	.	.02	.02	.	.	.10	.	.	.05	.18	.	2.25
Lake Basin.																						
Erie,†	.12	.06	.54	.01	.	.	.	.04	.	.15	.06	.08	.	.	.	.	.	.	.07	.13	.	1.41
																						4.08
																						1.60
																						1.93
																						4.07
																						1.77
																						3.23
																						4.10
																						1.91
																						2.32
																						2.46
																						1.67
																						1.70
																						2.35
																						2.71
																						1.88
																						2.48
																						2.46
																						2.42
																						4.21
																						3.94
																						2.22

8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	Total.
. .	. .	·07	. .	. .	. .	. .	·99	·10	. .	. .	. .	. .	. .	·13	·06	·03	·03	. .	. .	·11	. .	. .	. .	2·58
. .	. .	·11	. .	. .	. .	. .	·79	·18	·04	. .	·33	·08	. .	·17	·12	·07	·22	·05	. .	·02	·68	. .	. .	3·38
. .	. .	·20	. .	·05	·05	·01	·98	·20	·12	·03	·08	·18	. .	. .	·09	·08	·22	·18	. .	·19	·31	. .	·11	4·78
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. . .
. .	. .	·09	. .	. .	. .	. .	·76	·03	·01	. .	·01	·01	. .	·02	·03	·09	·05	. .	. .	·14	·72	·22	·12	2·98
. .	. .	. .	·08	. .	. .	. .	·90	·10	·04	. .	. .	. .	. .	·05	·05	·03	·02	. .	. .	·07	·40	·01	. .	2·88
. .	. .	. .	. .	. .	. .	. .	1·10	·12	·41	·03	·15	·08	. .	. .	. .	·16	·13	. .	. .	·09	·42	·08	. .	3·47
. .	. .	·06	. .	. .	. .	. .	1·48	·05	·19	·04	·01	. .	. .	·08	·10	. .	·08	. .	. .	·12	·25	. .	·05	3·67
. .	. .	·10	. .	. .	. .	. .	·65	·05	·13	. .	. .	. .	. .	·08	. .	·03	. .	. .	. .	·10	·40	·10	·05	2·37
. .	. .	·09	. .	. .	. .	. .	1·00	·25	. .	·06	. .	. .	. .	·10	·05	. .	. .	·04	. .	. .	·82	. .	·06	3·51
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. . .
. .	·02	·04	. .	. .	. .	·05	1·23	·12	·09	·02	·07	·03	·01	·02	·02	. .	·01	·09	. .	·07	·40	·01	·07	3·59
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. . .
. .	. .	·08	. .	. .	. .	. .	1·19	·06	·12	·03	·01	. .	. .	·06	·02	·06	·06	·03	. .	·08	·43	·16	·03	3·32
. .	. .	·10	. .	. .	. .	. .	1·31	·09	·11	·02	·05	·01	. .	. .	·11	·05	·19	·16	. .	·27	·46	. .	·04	4·46
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. . .
. .	·04	. .	·02	. .	. .	. .	·98	. .	·05	·03	·12	. .	. .	. .	·07	·05	·07	. .	. .	·30	. .	. .	·06	2·24
. .	. .	·14	. .	·01	·01	. .	1·04	·17	·09	·08	·40	·30	. .	·04	·13	·05	·08	. .	. .	·10	·58	·02	·03	4·63
. .	. .	·16	. .	·02	. .	. .	1·04	·10	·11	·03	·16	·03	. .	. .	·14	·02	·07	·15	. .	·24	·30	·02	·08	4·09
. .	·03	. .	. .	. .	·05	·01	·94	·12	·06	. .	·08	. .	·02	·03	·15	. .	·02	. .	. .	·19	·20	. .	·01	2·70
. .	·17	. .	. .	. .	·10	·80	·42	·10	·01	·08	. .	. .	. .	·18	·02	·02	·15	. .	. .	·62	. .	·05	. .	3·67
. .	·10	. .	. .	. .	·03	·42	1·27	·15	·20	·10	·15	. .	. .	. .	·25	. .	·05	·15	. .	·19	·04	. .	·05	3·71
. .	. .	·03	. .	. .	. .	. .	1·00	·06	·07	·01	·01	·02	. .	·03	·03	·02	·01	·04	. .	·05	·37	·11	·02	3·04
. .	. .	·08	·17	. .	. .	·60	·72	·08	·03	·15	·30	·05	. .	. .	·21	·05	·06	·38	. .	·03	·18	. .	·05	4·13
. .	. .	·25	·10	·15	. .	·45	1·35	·85	. .	·20	·02	. .	. .	. .	·25	·10	. .	·37	. .	. .	·25	. .	·08	6·07
. .	. .	. .	. .	. .	. .	. .	·35	·03	·12	. .	·09	. .	·05	. .	. .	. .	. .	. .	. .	. .	·82	. .	. .	1·75
. .	·04	·16	. .	. .	. .	. .	·86	. .	·20	·10	·12	.	·03	. .	. .	·12	. .	·17	. .	. .	·89	·12	·20	4·71
. .	·31	. .	. .	. .	. .	·11	1·37	·26	. .	. .	. .	. .	. .	·06	. .	. .	. .	·05	. .	·27	·82	. .	·15	4·11
. .	. .	·39	·02	·08	·03	·04	1·31	·11	·19	·10	·10	·19	·03	·04	·30	·11	·06	·36	·03	·08	·13	·02	·20	5·91
. .	. .	·05	. .	. .	. .	. .	1·10	·02	·16	·10	. .	. .	. .	·07	. .	·07	. .	·08	. .	·05	·38	·26	. .	3·31
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. . .
. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. .	. . .
. .	·15	·06	·08	. .	. .	·09	·38	·14	·18	·08	·08	. .	. .	·03	·03	·16	·07	·11	. .	·10	·02	·02	·10	2·65

Square, 3d, 5th, 30th; Phœnixville, 3d, 5th, 6th, 14th, 19th, 28th, 30th, 31st; Lock Haven, 3d, 14th, 18th, 30th; Bloomsburg, 4th, 14th, 15th, 17th, 28th, 30th, 31st; Saegerstown, 3d, 7th, 13th, 14th, 17th, 18th, 19th, 28th. 31st; Carlisle, 3d, 14th, 30th; Harrisburg, 3d, 5th, 14th, 30th, 31st; Uniontown, 1st, 2d, 31st; Huntingdon, 3d, 14th, 31st; Kilmer, 2d, 14th, 18th, 28th, 30th, 31st; Lancaster, 3d, 5th; New Castle, 1st, 2d, 4th, 11th, 17th, 18th, 19th, 31st; Lebanon, 3d, 5th, 14th, 15th, 19th, 30th, 31st; Drifton, 4th, 5th, 28th, 30th; Wilkes-Barre, 3d, 5th, 10th, 14th, 27th, 31st; Smethport, 1st, 3d, 4th, 11th, 12th, 14th, 15th, 18th, 19th, 31st; Pottstown, 4th, 5th, 30th; Aqueduct, 3d, 14th, 28th, 30th; *Philadelphia* [Centennial Avenue], 3d, 5th, 14th, 19th, 28th, 30th; Shingle House, 1st, 3d, 4th, 11th, 14th, 17th, 18th, 19th, 20th, 28th, 31st; Girardville, 2d, 3d, 5th, 14th, 28th, 30th, 31st; Selins Grove, 3d, 14th, 30th, 31st; Somerset, 1st, 3d, 16th, 18th, 20th, 29th; Dyberry, 3d, 5th, 14th, 15th, 28th, 30th, 31st; Honesdale, 3d, 5th, 14th, 19th, 30th, 31st; Salem Corners, 3d, 4th, 6th, 15th, 19th, 20th, 28th, 30th, 31st; South Eaton, 1st, 3d, 5th, 18th, 19th, 22d; York, 3d, 5th, 6th, 9th, 14th, 19th, 30th, 31st.

Sleet.—Altoona, 15th, 26th; Blue Knob, 1st, 3d, 14th, 26th; Hollidaysburg, 3d, 28th; Le Roy, 5th; Emporium, 15th; Coatesville, 2; Lock Haven, 14th, 29th, 30th; Saegerstown, 14th; Kilmer, 3d, 14th; *Philadelphia* [Centennial Avenue], 14th, 28th, 30th, 31st; Shingle House, 3d, 9th; Dyberry, 3d, 15th; York, 15th, 28th.

Aurora.—Westtown, 29th; Shingle House, 5th.

Coronæ.—Blue Knob, 15th; Emporium, 19th; Saegerstown, 17th, 18th; Lebanon, 16th, 17th, 18th, 21st.

Lunar Halo.—Hollidaysburg, 15th; Phœnixville, 15th; Westtown, 22d; Lancaster, 15th, 16th; Girardville, 20th; Dyberry, 24th.

Meteors.—State College, 7th, 10th; *Philadelphia* [Centennial Avenue], 6th, 13th.

Parhelias.—Blue Knob, 6th; Dyberry, 2d.

FEBRUARY WEATHER.

From United States Weather Bureau Records.

The following data, compiled from the records of observations taken during the length of time given at each station, show the average and extreme conditions during that time, and also the range within which weather variations may be expected to keep in any future February.

	Philadelphia. (22 years.)	Pittsburgh. (23 years.)	Erie. (20 years.)
Mean or normal, ...	34°	33°	28°
Warmest February, ...	1890	1871	1882
Average, ...	41°	43°	37°
Coldest February, ...	1885	1875	1875
Average, ...	24°	22°	16°
Highest temperature recorded, . . .	75°	76°	70°
Date, ...	23d, 1874	16th, 1883	16th, 1883
Lowest temperature recorded, . . .	Minus 2°	Minus 10°	Minus 16°
Date, ...	5th, 1886	15th, 1875	9th, 1875
Average date of first "killing" frost, ...	October 28th	October 21st	October 15th
Average precipitation (inches), . . .	3·28	2·90	3·55
Average number of days with ·01 inch or more, ...	12	15	17
Greatest monthly precipitation, . . .	5·70	6·52	8·50
Date, ...	1884	1887	1887
Least monthly precipitation, ...	0·84	0·85	0·33
Date, ...	1877	1871	1877
Greatest amount in 24 hours, ...	1·24	2·01	3·35
Date, ...	16th, 1873	26th, 1887	3d and 4th, 1883
Greatest amount snowfall in 24 hours,	8·00	5·30	3·50
Date, ...	3d, 1886	25th, 1885	27th, 1887
Average number clear days, ...	7	4	4
Partly cloudy, . .	10	11	10
Cloudy, ...	11	13	14
Prevailing direction of wind, ...	NW.	NW.	S.
Highest velocity, miles per hour, .	48	40	64
Date, ...	2d, 1876; 3d and 23d, 1880; 26th, 1886	26th, 1887	1875